# DISSERTATION

RAND

# Evaluating Future Force Options for the U.S. Army

## A Hybrid, Interactive, Multiple-Attribute, Exploratory Approach

John D. Pinder



RGSD-153

*RAND Graduate School*

Published 2000 by RAND
1700 Main Street, P.O. Box 2138, Santa Monica, CA 90407-2138
1200 South Hayes Street, Arlington, VA 22202-5050
RAND URL: http://www.rand.org/
To order RAND documents or to obtain additional information, contact RAND Distribution Services (Telephone: 310-451-7002; Fax: 310-451-6915; or Internet: order@rand.org). Abstracts of all RAND documents may be viewed on the World Wide Web (http://www.rand.org). Publications are distributed to the trade by National Book Network.

# DISSERTATION

RAND

# *Evaluating Future Force Options for the U.S. Army*

## *A Hybrid, Interactive, Multiple-Attribute, Exploratory Approach*

*John D. Pinder*

**RAND Graduate School**

*This document was prepared as a dissertation in June 2000 in partial fulfillment of the requirements of the doctoral degree in policy analysis at the RAND Graduate School of Policy Studies. The faculty committee that supervised and approved the dissertation consisted of Richard J. Hillestad (Chair), Steven C. Bankes, and Randall Steeb.*

## PREFACE

The purpose of this dissertation is to introduce and demonstrate a new approach to supporting high-level decisions. This new methodology, the hybrid, interactive, multiple-attribute, exploratory (HIMAX) process, combines multiple attribute decision making with exploratory modeling to integrate expert opinion to evaluate diverse options, with the intent of generating useful insights. The HIMAX process is demonstrated in this dissertation through an illustrative analysis of future military forces. The specific options considered, which include heavy armored, medium-weight, and light infantry forces, as well as tactical aircraft alone and in combination with special operations forces, are evaluated and compared across a wide spectrum of ground-oriented missions. The unique contribution of this work is the HIMAX process itself, and the mix of capabilities that it brings together, especially the ability to explore implications of divergent minority opinions.

This dissertation should be of interest to high-level decision makers, in the Army and the Department of Defense specifically, but also in other large private and public organizations. It should also be of interest to scholars of decision analysis and operations research, and practitioners of policy analysis, defense planning, and business strategy.

This research was supported, in part, by the Force Development and Technology Program of RAND's Arroyo Center, a federally funded research and development center sponsored by the United Stated Army.

## CONTENTS

# FIGURES

# TABLES

## ACKNOWLEDGMENTS

First and foremost, I must thank the members of my dissertation committee: Dick Hillestad, Steve Bankes and Randy Steeb. I am indebted to them for the effort they put into reading this dissertation under significant time constraints; their thoughtful criticisms and suggestions ultimately made this a sounder and more coherent document. I also have to extend special thanks to Randy Steeb, who has been a true mentor to me throughout my time at RAND, providing me with professional advice, and guiding me through the process of developing the idea for this dissertation and making it a reality. Innumerable impromptu discussions with Randy contributed greatly to this work, and helped shape its final form.

I am grateful to David Chu and Ken Horn of RAND's Arroyo Center for the financial assistance they made available to support the completion of this dissertation. This funding played a crucial role in expediting my work, by allowing me to concentrate my full effort on performing the necessary analysis and writing this document over the last several months.

The analysis presented in this dissertation would not have been possible without the participation of eight people, who acted as experts in the evaluation process: Russ Glenn, John Gordon, David Oaks, David Owen, Bruce Pirnie, Carl Rhodes, Steve Strukel, and Alan Vick. I am extremely grateful to them for the time and concentration that they devoted—without any compensation—to making the many careful assessments that the analysis required.

Special thanks are also in order for Professor Paul Bracken of Yale University, who read a draft of this dissertation, and provided a frank and constructive critique. His comments were especially valuable because they helped make the dissertation more comprehensible and easier to read. I must also thank Paul Davis specifically for his efforts in facilitating Professor Bracken's

participation, but also more generally for his intellectual leadership in defense analysis and policy modeling as a member of the faculty of the RAND Graduate School.

Many other members of the RAND Graduate School community provided useful advice through informal conversations. I am thankful, in particular, to the Dean of the RAND Graduate School, Bob Klitgaard, for his encouragement and guidance at a number of key moments in the dissertation process. I also want to thank my friend and colleague, John Stillion, who was always willing to listen to my ideas, explanations, and even complaints.

My highly capable, and always enthusiastic, secretary Linda Weiss deserves considerable praise. Her initiative and competence always kept me out of trouble, and enabled me to focus on my work. In addition, the interest she showed in my progress, and her eagerness to listen, were together a great help.

I cannot begin to express the depth of my gratitude towards my partner in life, Svjetlana Tepavcevic, whose love, support, and occasional spurring, have carried me through this trying experience. I also must thank my mother, Joan Pinder, for her patient and persistent encouragement over the course of my long and winding academic journey. My late father, Noel Pinder, was not able to share in this odyssey, so I dedicate its culmination—this dissertation—to him. His dedication to excellence and integrity is my inspiration.

## GLOSSARY

| Name or Acronym | Description or Definition |
|---|---|
| A-10 | Thunderbolt armored ground-attack aircraft |
| ADE | Average Differential Effect |
| AEF | Air Expeditionary Force |
| AFSS | Advanced Fire Support System |
| AH-64D | Apache Longbow Attack Helicopter |
| AHMV | Advanced High-Mobility Vehicle |
| AHP | Analytic Hierarchy Process |
| AOA | Analysis of Alternatives |
| AP | Armor Piercing |
| APC | Armored Personnel Carrier |
| APS | Active Protection System |
| ARES | Advanced Robotic Engagement System |
| ARSS | Average Rank Shift Sum |
| ATACMS | Army Tactical Missile System |
| ATGM | Anti-Tank Guided Missile |
| BAT | Brilliant Anti-Tank |
| C-130 | Hercules intratheater transport aircraft |
| C-17 | Globemaster III heavy-cargo transport aircraft |
| $C^3$ | Command, Control and Communications |
| C-5 | Galaxy heavy-cargo transport aircraft |
| COEA | Cost and Operational Effectiveness Analysis |
| Crusader | A new self-propelled howitzer and resupply vehicle |
| DARPA | Defense Advanced Research Projects Agency |
| DPICM | Dual-Purpose Improved Conventional Munition |
| DynaRank | A high-level, spreadsheet-based decision support system developed at RAND |
| EFOG-M | Enhanced Fiber-Optic-Guided Missile |

| | |
|---|---|
| EFP | Explosively Formed Projectile |
| EM | Electromagnetic radiation |
| FCS | Future Combat System |
| FOTT | Follow-on-to-TOW |
| FS | Fin-Stabilized |
| FSCS | Future Scout Cavalry System |
| HIMARS | High-Mobility Artillery Rocket System |
| HIMAX | Hybrid, Interactive, Multiple-Attribute, Exploratory |
| HMMWV | High-Mobility Multi-Wheeled Vehicles |
| IFV | Infantry Fighting Vehicle |
| IR | Infrared radiation |
| ISR | Intelligence, Surveillance and Reconnaissance |
| Janus | A high-fidelity, force-on-force simulation |
| Javelin | A new hand-held anti-tank missile system |
| JSF | Joint Strike Fighter |
| JSTARS | Joint Surveillance Target Attack Radar System |
| JTR | Joint Tactical Rotorcraft |
| KEP | Kinetic Energy Penetrator |
| LAV | Light Armored Vehicle |
| LOSAT | Line-Of-Sight Anti-Tank missile |
| M109A6 | Paladin self-propelled howitzer |
| M1A2 | Abrams main battle tank, latest version |
| M1A3 | Abrams main battle tank, notional future version |
| M2A3 | Bradley fighting vehicle, latest infantry version |
| M2A4 | Bradley fighting vehicle, notional future version |
| M3A3 | Bradley fighting vehicle, latest cavalry version |
| MADM | Multiple Attribute Decision Making |
| MBT | Main Battle Tank |
| MLRS | Multiple Launch Rocket System |
| Monte Carlo | A type of simulation in which random numbers are drawn for every probabilistic variable in each run |

| | |
|---|---|
| NASA | National Aeronautics and Space Administration |
| NTACMS | Navy Tactical Missile System |
| P3I | Pre-Planned Product Improvement |
| PGM | Precision-Guided Munitions |
| QDR | Quadrennial Defense Review |
| R&D | Research and Development |
| RAH-66 | Comanche Reconnaissance-Attack Helicopter |
| RHA | Rolled Homogeneous Armor |
| RORO | Roll-On/Roll-Off |
| RPG | Rocket-Propelled Grenade |
| RST | Reconnaissance, Surveillance, and Target Acquisition |
| RST-V | Reconnaissance, Surveillance and Target Acquisition Vehicle |
| SADARM | Sense and Destroy Armor (anti-tank munition) |
| SAW | Simple Additive Weights |
| SOF | Special Operations Forces |
| SPH | Self-Propelled Howitzer |
| SSTOL | Super-Short Take-Off and Landing |
| TAC-AIR | Tactical Aircraft |
| TOPSIS | Technique for Order Preference by Similarity to Ideal Solution |
| TOW | Tube-launched, Optically-guided, Wire-guided missile |
| UAV | Unmanned Arial Vehicle |
| UGS | Unattended Ground Sensor |
| V-22 | Osprey tilt-rotor aircraft |
| VAA | Value Added Analysis |
| WPM | Weighted Product Method |

# 1. INTRODUCTION

Leaders in large organizations often face tough policy decisions involving complex systems and considerable uncertainty. They must consider how a wide range of options contribute to conflicting objectives in a variety of situations, and then rely on a mixture of intuition and expert advice to make their final choice. This dissertation introduces a new type of decision support process that can assist decision makers when they are in this sort of predicament. This hybrid, interactive, multiple-attribute, exploratory (HIMAX) approach is a substantial improvement over traditional decision-support methods because it incorporates complexity and uncertainty, and explores the implications of minority opinions among expert advisors, providing insights that other methods might miss. To demonstrate this new approach and illustrate its capabilities, this dissertation presents an analysis of future force options using the HIMAX process. This analysis yields useful insights and provocative observations regarding the dilemma confronting the U.S. Army today, indicating that the HIMAX process could be used to inform high-level policy choices in other contexts as well.

## 1.1 THE ARMY'S DILEMMA

As it stands at the dawn of 21$^{st}$ Century, the U.S. Army faces a turbulent and daunting future. If the trends of the 1990s continue, the early decades of the next century will be characterized by both strategic uncertainty and regional instability. While a great power on a par with the U.S. is unlikely to emerge in this time frame, regional powers, rogue states, and even transnational organizations may threaten U.S. interests around the world in a variety of ways, with very little warning. Thus, the greatest challenges facing the Army will stem from the frequency, diversity, novelty and complexity—rather than the intensity—of future conflicts. To be both effective and efficient (and relevant) in this type of future the Army must be able to respond quickly and decisively to a wide

range of contingencies, and then achieve a swift victory with few casualties and minimal logistic support. While engaged in such a conflict, the Army must also fulfill its existing commitments around the world, and remain ready to respond to other similar incidents.

The Army of today, with its Cold-War heritage, is not well-suited for such a dynamic and unstable security environment. Its armored divisions are very heavy and require extensive support, so they are extremely costly and slow to deploy, especially in areas with no existing infrastructure. The Army's lighter forces—the 82nd Airborne and 10th Mountain Divisions—can be deployed much more rapidly and require considerably less support, but they do not have enough mobility, protection and firepower to be effective on their own; if overmatched they could be ineffective and sustain high casualties. The Army may be able to serve U.S. interests more effectively in the emerging environment if it can bridge the gap in its current mix of capabilities with a balanced "medium-weight" force; a new type of force that is more deployable and sustainable than heavy armored units, yet more mobile, potent and survivable than light infantry forces (Gordon and Wilson, 1998, 1999). Indeed, the Army adopted a new vision in 1999 that dedicates it to moving in the direction of medium-weight forces (Shinseki, 1999). The dilemma, of course, lies in the details of this transformation; a force that is more deployable and sustainable will tend to be weaker and more vulnerable. Tradeoffs like this need to be evaluated to determine whether new medium-weight forces can deliver the benefits that they are intended to provide.

## 1.2 MOTIVATION FOR A NEW APPROACH

This sort of predicament is not unique to the Army. Overtaken by external events, large organizations sometimes find themselves with a base of human, social and physical capital that is inappropriate for their new circumstances. In this moment of truth, the organization's leaders can make better decisions if they have a coherent way of merging input from a diverse group of expert advisors to

evaluate and compare, refine or expand, and then reassess their options. If, however, the systems involved are complex, and the context is highly uncertain, simply aggregating expert evaluations of the alternatives may neglect important synergies and sensitivities, and thus produce misleading results. In this sort of environment, a decision support process is most effective if it can combine five important capabilities: capturing synergistic interactions, reconciling conflicting objectives, comparing diverse options across multiple missions, representing uncertainty explicitly, and exploring implications of divergent minority opinions.

Conventional approaches to the analysis of strategic decision making, especially those involving military forces, tend to be weak in one or more of these important capabilities, while the HIMAX process, which this dissertation describes and demonstrates, incorporates features that address all five of them. A customized evaluation model at the core of the HIMAX process combines multiple option attributes, which are each linked to a key strategic objective. The detailed structure of this model is designed to capture synergies within each option by deriving its attributes from the characteristics of its components, using expert input to determine the relevant parameters. After seeing a summary of the preliminary results, the experts can refine their initial assessments and suggest new or modified options. The parallel nature of the model[1] allows several options to be evaluated simultaneously for a select set of situations. Uncertainty in technological performance is represented explicitly, and propagated through the model, providing confidence intervals on the outcomes for each option. The effects of perturbations in the model's parameters are systematically explored to highlight the potential impact of expert assessment errors. Most importantly, minority opinions among the experts are used to guide and focus exploration, rather than ignoring them and relying exclusively on the group consensus. The

---

[1] The customized version of the HIMAX process used in this analysis is implemented with Analytica™, a visual modeling tool developed by Lumina Decision Systems.

insights gained from this type of informed exploration can then be used to slant and color how the final results of the analysis are interpreted.

## 1.3 OBJECTIVE OF THE ANALYSIS

This dissertation describes the HIMAX process in detail, and then applies it to an analysis of future force options. The objective of this analysis is two-fold. First, it aims to provide insights and observations regarding policy choices facing the Army today. Second, and more importantly, it intends to demonstrate that the HIMAX process is an effective way to support high-level policy decisions, and could be applied to inform equally challenging choices in other areas.

The analysis compares five force options—heavy armored, medium-weight, light infantry, air-only standoff, and special operations teams with standoff—in two time frames: the near term (2005–2010) and the far term (2015–2025). The near-term options are more evolutionary in nature, as compared to today's forces, while the far-term options include some more revolutionary capabilities that would require significant technological breakthroughs. The HIMAX evaluation model was, of course, customized to assess and compare such a diverse set of military force options, and eight people, drawn from the RAND research staff and visiting military fellows, served as experts by providing the input needed to determine the model parameters.

By generating genuine insights into the decisions facing the Army in the early part of the 21st Century, and then providing policy observations based on these insights, this research makes a substantial contribution to the ongoing policy debate on the transformation of the Army, and provides a framework for further analysis. The customized evaluation model developed for this analysis is also appropriate for other similarly complex defense planning problems. With some modifications, the HIMAX process could be applied to high-level decisions in a variety of contexts, especially those that are highly uncertain and involve complex systems, like infrastructure protection or space exploration.

## 1.4 ORGANIZATION OF THE DISSERTATION

The dissertation includes a total of twelve chapters. Chapter 2 discusses the motivation for a new high-level decision-support methodology, and how the HIMAX process is designed to address it. Chapter 3 presents the methodology of the HIMAX process in detail. Chapter 4 describes how the evaluation model was customized to assess and compare military force options. Chapter 5 discusses the structure of the analysis conducted to demonstrate this process, and provides details on the composition of the options under consideration. Chapters 6 through 10 present and discuss the results of the first five phases in the HIMAX process: preparation, generation, evaluation, prioritization and exploration. No chapter is devoted to the sixth and final phase, interaction, since this phase was not included in the analysis. Chapter 11 serves a similar function, however, re-analyzing the HIMAX results from a prescriptive perspective, and drawing out insights to provide a basis for several observations regarding the policy choices facing the Army. Chapter 12 wraps up the dissertation with a review of the advantages and limitations of the HIMAX process, in light of its performance in the analysis, a discussion of several possible improvements, and descriptions of a few ideas for future applications.

The dissertation also includes two appendices. Appendix A describes the assumptions made about opposing forces in order to determine the floor of the effectiveness scale used in the evaluation model. Appendix B provides some background information on the people who participated as experts in the demonstration analysis.

# 2. MOTIVATION FOR A NEW METHODOLOGY

High-level decision makers often rely on a mixture of their own intuition and advice from a host of experts to inform complex policy choices, especially in highly uncertain contexts. An effective decision support process could help them greatly by coordinating assessments from a group of experts, and using their inputs to evaluate specific options with a decision model that captures both the complexity of the problem and the uncertainty of its context. Of course, the purpose of such a process is to support decisions, not make them; it should generate insights into the choices facing decision makers, which they can then integrate with their intuition to choose a course of action. The HIMAX process addresses this need by combining five vitally important capabilities, which are described at the outset. The rest of the chapter reviews previous work that provides a foundation for the HIMAX approach, discusses how this new technique provides each key capability, and then compares it to conventional methods used to evaluate military force options—the specific problem that this dissertation focuses on as an illustrative example.

## 2.1 IMPORTANT DECISION-SUPPORT CAPABILITIES

In an environment characterized by complexity and uncertainty, high-level decision makers need a support process that can capture synergistic interactions, reconcile conflicting objectives, compare diverse options across multiple missions, represent uncertainty explicitly, and, above all, explore implications of divergent minority opinions. These capabilities reflect the nature of a broad class of policy problems, and address the challenges associated with them. In such problems, the options being considered are complex, consisting of numerous components of different types that can interact with each other synergistically. The objectives are often in conflict, with options contributing more to some objectives and less to others. Given this complexity, it is prudent to consider a

number of different options, and then evaluate them across a broad range of situations. In addition, the performance of individual option components and the overall nature of the future are both inherently uncertain. Most importantly, because such problems are so broad and complex, they require input from a wide variety of experts, who will inevitably disagree on crucial tradeoffs and assessments. Plausible minority opinions among these experts could have important implications that would generate provocative insights.

Evaluating military force options in today's defense planning environment[2] is exactly this type of problem. The future appears likely to present U.S. forces, especially the Army, with significant challenges that are distinctly different from those they faced during the Cold War. Extrapolating from current trends, the most recent Quadrennial Defense Review (QDR) envisions a future characterized by strategic uncertainty and regional instability, and states that U.S. forces must change and innovate in order to "achieve new levels of effectiveness across the range of conflict scenarios" (Cohen, 1997). In 1999, the new Army Chief of Staff, General Eric K. Shinseki, unveiled a new vision for the Army, which aims to achieve "strategic dominance across the entire spectrum of operations" by transforming its forces into new "medium-weight" brigades that are much more deployable and sustainable than today's heavy armored forces, yet just as formidable (Shinseki, 1999). Given the challenges that this transformation poses, and the complexity and uncertainty of the future security environment, Army force planners need an approach to force evaluation that will enable them to make difficult tradeoffs and allocate scarce resources with greater confidence. In short, they need a decision support process that combines the key capabilities enumerated above. The following descriptions of these capabilities frame them in a manner that addresses the special needs of force evaluation.

--------

[2] Khalilzad and Ochmanek (1997), O'Hanlon (1995) and Davis (1994) provide a variety of recent perspectives on U.S. defense planning.

# Motivation

*Capture synergistic interactions between systems and operational concepts.* In an effort to prepare for the future, the Army is contemplating significant changes in force structure, organization and operational doctrine. The innovations at the heart of these new force concepts often rely on a "system-of-systems" approach to integrate radically new tactics with advanced sensor and weapons systems. Ultimately, the synergy associated with these force concepts is what makes them so attractive. Thus, some ability to capture synergistic interactions among systems and operational concepts is essential.

*Combine multiple objectives to measure force effectiveness.* For a force evaluation to be useful at the level where force structure decisions are made it must, in the end, compress a complex array of information regarding multiple objectives into comprehensible measures of overall value and effectiveness. At the same time, this process should be flexible enough to allow top-level decision makers to take other important factors, like risk and cost, into account.

*Consider many different force options and potential missions.* Strategic uncertainty and regional instability appear likely to dominate the international security scene in the coming decades. To prepare for such a future, U.S. defense planners must be able to evaluate many different force options over a wide range of plausible scenarios. A broad set of evaluations will enable them to rate and compare options based on their effectiveness in key missions, as well as their robustness across the full spectrum of possible operations.

*Represent uncertainty in option performance explicitly.* Uncertainty plays a very important role in many of today's future force planning problems. The exact characteristics of a system or operational concept can depend on a variety of technological and environmental factors. In addition, some force components incorporate technologies that are sufficiently advanced that their performance is highly uncertain and subject to considerable development risk. Treating such uncertainty explicitly can provide valuable insights and help paint a much clearer picture of tradeoffs among the force options, even at the strategic level.

*Explore the implications of divergent minority opinions.* It is very unlikely that a diverse group of experts will agree on all of the assessments they have to make. In fact, certain experts will probably have opinions that diverge significantly, and systematically, from the median opinion of the group. Since the experts have different backgrounds and experiences, their views may differ in a coherent way, straying the most from the mainstream on a number of related assessments. Observing the impact of using such systematically divergent responses instead of the consensus ratings should provide important insights into the sensitivity of the results to plausible differences of opinion. This is an extremely valuable analytical capability in a contentious planning environment, where high-level decisions will have far-reaching consequences throughout an organization.

## 2.2 REVIEW OF PREVIOUS WORK

As its name indicates, the HIMAX process is a hybrid approach, which integrates a mixture of multiple-attribute decision making (MADM) techniques with the mindset and methods of exploratory modeling. Since this method involves a new application of exploratory modeling, the previous work in this field is reviewed first. This discussion is followed by a brief overview of the roots and methods of MADM.

### Exploratory Modeling

Exploratory modeling was developed at RAND during the early 1990s, and has been applied in a variety of different policy areas, including technology, the environment, education, and defense. Bankes (1993) introduces exploratory modeling, defining it as "using computational experiments to assist in reasoning about systems where there is significant uncertainty," and discusses its potential applications to policy analysis. The rapid expansion in computing capabilities over the past two decades has, as Bankes (1994) points out, created opportunities for new, exploratory modes of modeling and analysis. In an early application of exploratory modeling, Lempert , Schlesinger and Bankes (1996) evaluate static

and adaptive strategies for reducing the impact of global climate change, and then depict where each policy is the most effective in a space of possible futures.

Davis, Gompert and Kugler (1996) highlight the opportunities for using exploratory modeling to represent and evaluate adaptive strategies in defense planning. In a weapon mix analysis, Brooks, Bankes and Bennett (1997) show quite convincingly that this approach can go beyond optimization and sensitivity analysis to comprehensively search the space of possibilities for other, potentially very different, combinations of inputs that are very nearly as attractive as the optimal solution. Davis, Bigelow and McEver (1999) show how exploratory analysis can apply multi-resolution combat modeling to evaluate how effective alternative force options are across a wide range of combat scenarios, using a new visualization tool (Data View) to depict the results. Lempert and Bonomo (1998) use an exploratory technique to examine the implications of the choices that two groups of experts made in a web-mediated science and technology planning exercise. Dewar et al. (2000) model the process of expanding the Army for a major war or confrontation, using exploration to highlight the effects and implications of key constraints and bottlenecks.

All of these analyses illustrate the impact of uncertainty, and in so doing generate insights into the nature of the problem or system under consideration. This dissertation aims to do the same, introducing and demonstrating the HIMAX process as a new application of exploratory modeling, drawing on elements of all these other examples—relying on expert participation, analyzing sensitivity comprehensively, and visualizing the effects of uncertainty. It adds to this body of work in two ways: first, it models complex decisions using expert assessments of key tradeoffs, rather than detailed combat simulations; and second, it relies on patterns in the expert inputs to guide and focus exploration.

## Multiple Attribute Decision Making

There is a vast body of literature on MADM[3], which has its roots in economics, game theory, decision analysis and operations research. Yoon and Hwang (1995) explain that the decision models in this field generally take one of two forms: *normative* models that aim to find the optimal solution to a design or allocation problem, using rational rules for how choices should be made; or *descriptive* models that evaluate alternative options, based on how people really make decisions (Tversky and Kahneman, 1974, 1981). Bell, Raiffa and Tversky (1988) refer to MADM methods that can be used for both purposes as *prescriptive*. The HIMAX process is primarily a descriptive method[4], but it does have normative aspects, so it can also be used prescriptively.

The essential first step in any MADM method is to select and specify a set of key attributes, and then define a function or procedure for evaluating options based on their attribute levels. Keeney and Raiffa (1993) describe the properties that the set of attributes should have, emphasizing that each member should be linked to a primary objective of the problem. They also use value functions that are consistent with the standard utility theory described by Von Neumann and Morgenstern (1947) to evaluate options or find optimal solutions. Other prominent works, in a variety of contexts, also advocate the use of multiattribute utility theory: Zeleny (1982) for management, Winterfeldt and Edwards (1986) for decision analysis, Steuer (1986) for operations research, and Edwards and Newman (1982) for project evaluation. This approach is appealing because it provides an absolute scale for measuring the value of an option. Relative value

---

[3] In this literature, the words "objective" and "criteria" are often used instead of the word "attribute." While there are subtle differences in what these three different terms generally refer to, they all aim to address the same sorts of problems.

[4] The HIMAX process does not employ conjoint analysis, a descriptive approach used widely in marketing (Louviere, 1988). This method requires extensive data to design an overall objective function that includes interactive terms to better represent actual decision making

measurements, however, may provide a better picture of true preferences, but could violate attractive axioms of utility theory, like the independence of irrelevant alternatives or transitivity. Nonetheless, many popular MADM methods rely on descriptive measurement techniques.

Yoon and Hwang (1995) provide an excellent overview of these MADM methods, presenting them in two distinct categories: *compensatory* methods that allow the stronger attributes of an option to make up for its weaknesses, and *non-compensatory* methods that do not permit such tradeoffs. Non-compensatory methods include dominance, satisficing (Simon, 1957), sequential elimination and attitude orientation. The most basic compensatory methods calculate weighted scores for each option, using either Simple Additive Weights (SAW) or the Weighted Product Method (WPM). The Analytic Hierarchy Process (AHP) developed by Saaty (1980) constructs a hierarchy that links options to objectives, and then uses pair-wise assessments of relative value, along with the mathematics of matrix analysis, to determine the weights used in its scoring calculations. Hwang and Yoon (1981) introduce the Technique for Order Preference by Similarity to Ideal Solution (TOPSIS), which evaluates options geometrically, based on how close they are to a positive ideal solution, and how far they are from a negative ideal solution. Hwang and Lin (1987) examines how such multiple attribute methods can be extended to group decision making. Elements of all these methods are used in the hybrid approach to MADM that the HIMAX process employs.

## 2.3 STRUCTURE AND CAPABILITIES OF THE HIMAX PROCESS

Before discussing how the HIMAX process provides the key decision-support capabilities identified earlier, in Section 2.1, it is helpful to describe the structure of this process, which consists of six phases: preparation, generation,

---

behavior. The customized version of the HIMAX decision model used in this analysis does, however, use a simpler approach to capture synergistic interactions within the options.

evaluation, prioritization, exploration and interaction. The model is customized at the outset of the preparation phase, and then the experts make a variety of assessments that determine the parameters of the customized evaluation model. The options under consideration are defined and characterized in the generation phase, and then evaluated in the third phase of the process. In the prioritization phase, the options are screened, and selected pairs are compared across a range of futures. The effects of many different perturbations in the expert inputs, and compositional alterations in the options, are examined during the exploration phase. In the final phase of the HIMAX process, the experts have a chance to see the preliminary results, revise their assessments, and even suggest changes in the options, prior to a final re-evaluation. The sequential organization of these phases in the HIMAX process is depicted in Figure 2.1.

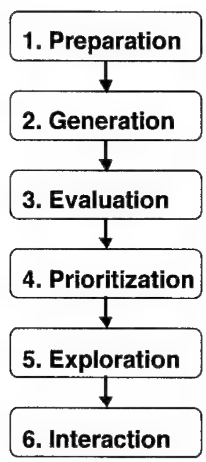



**Figure 2.1. The Six-Phase HIMAX Process**

In the illustrative demonstration analysis, this process is used to evaluate several military force *options*. These options are composed of *systems*, like tanks and helicopters, and *operational concepts*, such as maneuver warfare, which dictate how the systems are used together in a force. The physical or behavioral properties of a force component are represented by *ratings* on a number of *characteristics*, like the mobility of a system, or the awareness associated with an operational concept. The ratings are integers selected from an ordinal 1-to-9

scale specifically designed for each characteristic. Since the intervals between scale levels are not always equal, a *value function* is assigned to each characteristic that converts the integer ratings of a force component to a set of corresponding *values*. The value function assigned to mobility, for instance, might map a rating of 3 to a value of 4.1. The values of the components of an option on a given characteristic are used to derive the *force-level* value for that characteristic of the option as a whole. For example, if an option consisted of tanks and helicopters, which have mobility values of 4.1 and 7.5, respectively, the force-level value for the option's mobility might be 5.5. The force-level characteristics of an option are used to determine its *attributes*, which are each linked to an objective for the force, with some characteristics contributing more to some attributes than to others. For example, the attribute survivability, which is linked to the objective of minimizing casualties, might rely more on the characteristic protection than on mobility or awareness. The attribute levels of an option are then weighted differently for each mission, to calculate its *effectiveness* for that mission. These effectiveness outcomes are also weighted in the prioritization phase, based on the prevalence of each mission, to determine the overall *strategic value* of an option.

The particular techniques and methods used by the HIMAX process enable it to combine the five key capabilities that are essential in the current defense planning environment, and are so important in complex decision problems that are fraught with uncertainty, more generally. The following paragraphs describe how the HIMAX process provides each of these important capabilities.

*Capture synergistic interactions between systems and operational concepts*. The evaluation model captures synergistic effects by separately considering the characteristics of the systems and operational concepts that comprise a particular force option, and then linking them, both individually and in combination, to the attributes of the force. Also, to further illustrate the impact of such interactions, the experts are exposed to the initial results and findings of the HIMAX process.

They are then given an opportunity to refine their assessments to account for unanticipated or underestimated synergistic effects.

*Combine multiple objectives to measure force effectiveness.* The core of the HIMAX approach is a two-stage multiple attribute evaluation model. The first stage characterizes the specific force options that are under consideration and determines how they rate in terms of several generic attributes, each of which is associated with a broad capability objective. The second stage then weights these attributes differently for every potential mission to calculate a measure of effectiveness for each force option. Both stages rely on expert assessments gathered in the preparation phase to determine the structure and parameters of the model.

*Consider many different force options and potential missions.* The relatively simple formulation of the evaluation model allows many different force options and missions to be evaluated simultaneously.[5] Once the structure of the model has been customized, the potential missions chosen, and the components of the force options characterized, then weights derived from the expert assessments are applied to every combination of force option and mission. The exact number of expert assessments needed depends largely on the customized structure of the evaluation model, and is independent of the number of force options considered, although it does increase if more potential missions are included.[6] Thus, adding extra force options would have only a marginal effect on the amount of effort required to apply the HIMAX process, provided that they are composed of systems that have already been fully characterized.

--------

[5] This capability is possible because complex decision models that use multi-dimensional variable arrays can be constructed with Analytica™.

[6] The ratings required to characterize each force component are based on technological projections, so they are not "expert assessments" in the sense discussed here. If these technological ratings are made by the same experts, then the total number of assessments they need to perform will be dependent on the number of components in the force options considered.

*Represent uncertainty in option performance explicitly.* The structure of the HIMAX process allows uncertainty to be examined at three levels: technological, operational, and strategic. Discrete probability distributions in the characteristics of each force component are included to capture the uncertainty in technological performance. The resulting value distributions for each characteristic are aggregated across every option and propagated through the evaluation model to determine distributions in mission effectiveness. The impact of operational uncertainty is explored by examining the effects of small perturbations in the expert assessments, and incremental adjustments in force composition. Finally, the implications of strategic uncertainty are investigated by comparing the effectiveness of each force option across all missions, both parametrically and for a number of scenarios that represent plausible, but distinctly different futures.

*Explore the implications of divergent minority opinions.* The entire fifth phase of the HIMAX process is devoted to exploration. Trying every possible combination of deviations from the baseline model parameters would be the ideal way to explore, but this would consume excessive amounts of time and computer memory, and probably yield very little for the amount of effort expended. The HIMAX process uses a more efficient type of exploration, which takes advantage of the diversity of opinion among the experts. The largest deviations of expert assessments from the aggregate (i.e., median) values used in the baseline analysis are examined, and those that have a large impact on option preferences, are related in some way, and are associated with the same expert, are combined together. Examining the impact of these joint deviations provides interesting and useful insights because they represent plausible differences of opinion that have a substantial effect on the outcomes of the analysis. Such insights allow the results to be interpreted in a more thoughtful manner, so that they can form the basis for subtle and well-reasoned policy observations.

## 2.4 COMPARISON OF MILITARY FORCE EVALUATION TECHNIQUES

Military force options have conventionally been evaluated using techniques that can be placed into one of three broad categories: technical analysis and modeling of individual systems; force-on-force combat simulation; and decision support tools based on expert assessment. These different classes of methods generally have certain strengths and weaknesses in terms of the five capabilities that are considered essential in the current defense planning context. Table 2.1 provides a rough assessment the three categories, plus the HIMAX process, with respect to each of the five essential capabilities. Obviously, these assessments are generalizations, so the reasoning behind the rating assigned to each category is discussed below, along with an illustrative example.

**Table 2.1**

**Assessment of Force Evaluation Techniques with Respect to Decision Support Capabilities Considered Essential in the Current Defense Planning Context**

| Category of Force Evaluation Techniques | Essential Capability | | | | |
|---|---|---|---|---|---|
| | *Capture Synergistic Interactions* | *Combine Multiple Objectives* | *Consider Many Options and Missions* | *Represent Uncertainty Explicitly* | *Explore Divergent Minority Opinions* |
| *Technical Analysis and Modeling of Individual Systems* | WEAK | STRONG | WEAK | MODERATE | WEAK |
| *Force-on-Force Combat Simulation* | STRONG | WEAK | WEAK | MODERATE | WEAK |
| *Decision Support Tools Based on Expert Assessment* | WEAK | STRONG | STRONG | MODERATE | WEAK |
| *The HIMAX Process* | MODERATE | STRONG | STRONG | STRONG | STRONG |

### Technical Analysis and Modeling of Individual Systems

This category encompasses a variety of approaches ranging from engineering-level models to performance rating schemes. These techniques usually combine multiple objectives to assess overall technical performance. Because they focus on a single system, however, these assessments generally do not capture synergistic interactions among multiple systems, or consider specific operational factors across a range of different missions. These techniques do sometimes include uncertainty, but only to account for events or conditions that affect technical performance.

The traditional method of evaluating tanks provides an excellent example of this type of approach. Ever since tanks were first used in combat during the First World War, the same three factors—firepower, protection, and mobility—have been considered the principal contributors to a tank's fighting value. To quantify the tradeoffs between these factors, and compare different tank designs, a measurable proxy is often associated with each factor (e.g.: main gun muzzle energy for firepower; effective frontal armor thickness for protection; and engine power to weight ratio for mobility), so that any tank design can be represented by a "technical tank triangle." Such triangles are formed by plotting the value of each proxy on a separate axis, and then connecting the points on adjacent axes (which are separated by 120°). The area of this triangle acts as a rough measure of overall fighting value, while its "shape" (i.e., the relative mix among the three factors) is an indication of the design philosophy (Ischebeck and Spitzer, 1992; Simpkin, 1979).

## Force-on-Force Combat Simulation

The principal advantage of force-on-force combat simulation[7] over other force evaluation methods is its ability to represent interactions among individual systems, which captures some of the synergy, both beneficial and detrimental, that may exist within a force. These simulations require a level of detail that can makes them so large and cumbersome that they can only be used to examine a handful of force options in a few missions. While uncertainties associated with battlefield phenomenon are usually included in these simulations, assessment errors and technological or operational deficiencies are usually not represented explicitly. Also, simulation analysis tends to focus on a single measure of effectiveness, such as the loss exchange ratio, rather than integrating multiple objectives in a formal manner.[8]

For example, Matsumura et al. (1997) use force-on-force simulation to evaluate a variety of different types of ground force tactics and technologies. The Janus high-resolution simulation used in this analysis represents individual systems as separate entities and captures the interactions among them as it recreates realistic operational engagements. The behavior of entities in Janus is scripted, however, so they cannot revise or adapt their plans as an engagement unfolds. Even so, because they capture system interactions in so much detail, such simulation results provide an indication of when and how synergy can affect force effectiveness.

---

[7] Force-on-force simulations model engagements between military forces that consist of multiple brigades, or even a few divisions. Individual systems and weapons are represented as separate entities, and can interact with one another according to rules that capture environmental conditions and performance characteristics.

[8] For an extensive discussion of the difficulties associated with aggregating detailed, high-resolution combat simulation results, see Davis and Blumenthal (1991). A more formal treatment of this problem and some illustrative examples can be found in Davis and Bigelow (1998).

## Motivation

### Decision Support Tools Based on Expert Assessment

A variety of different decision support tools are used to evaluate, compare, and select military force options. These techniques are most often applied to high-level decisions regarding the acquisition of new systems, under the rubrics of Cost & Operational Effectiveness Analysis (COEA), Analysis of Alternatives (AOA), and Value Added Analysis (VAA). These applications usually rely on SAW, or a more sophisticated MADM method, like the AHP (Saaty, 1980) or TOPSIS (Hwang and Yoon, 1981), to evaluate options with respect to multiple objectives, using a mixture of expert assessments and combat simulation results (Koury and Loerch, 1992; Gaertner, 2000). These schemes are usually flexible enough to evaluate many different options and missions, provided that the necessary expert or simulation inputs are not too difficult or costly to obtain. The decision models at the core of these approaches are amenable to uncertainty analysis, but variations in system performance, operational factors, or expert opinions are not usually examined extensively, if at all. The principal weakness of techniques in this category is that they do a poor job of capturing nonlinear relationships, particularly with respect to system and operational interactions.

Hillestad and Davis (1998) introduce the DynaRank decision support system, an excellent example of this sort of technique, which they apply to the prepare-shape-respond strategy proposed in the most recent QDR (Cohen, 1997). DynaRank assists high-level decision-makers with critical strategic tradeoffs, using input from both subjective expert judgement, and the results of extensive modeling and simulation efforts. This system requires inputs that indicate the effectiveness for various force options across a range of scenarios. The process for generating these inputs, however, is specific to each application, and does not include non-linear interactions or an explicit representation of uncertainty. DynaRank does provide a useful framework for comparing the cost of various force options to their high-level strategic contributions, so another technique that

takes synergistic effects and uncertainty into account, like HIMAX, could complement it by providing it with better mission effectiveness inputs.

## The HIMAX Process

As Table 2.1 shows, the HIMAX process provides a more balanced mix of the five essential decision-support capabilities than any of the other categories. These conventional techniques may be equal or superior to the HIMAX approach in one or even two capability areas, but each of them is weak in at least one area, while HIMAX receives a moderate or strong rating in all five. The HIMAX process does, however, have a number of potential limitations that are worth highlighting.

First, it only represents a limited set of the possible synergistic interactions, and requires a large number of expert assessments to capture them, which may tire out the experts and reduce the quality and consistency of their responses. This may also be a problem for combining objectives, and considering multiple missions, though not to the same extent. Considering more options can also be a drawback, since characterizing the option components requires a lot of research prior to an analysis. While representing uncertainty explicitly in the HIMAX process is effective, the many required estimates may be speculative, and hence not entirely reliable. Finally, exploring minority opinions can be very tedious unless it is automated.

It is important to point out that the HIMAX process really belongs in the third category—decision support tools based on expert assessment. It includes some additional features, however, that remedy this category's weaknesses in a few key capabilities. The HIMAX process makes some attempt to capture synergistic interactions, while conventional decision support tools do not. In addition, the HIMAX approach does a better job of representing uncertainty than other decision support tools, and is the only method that explores implications of minority opinions. Taken together, the methodology of the HIMAX process,

which Chapter 3 describes in detail, provides a well-balance mix of the capabilities that are essential for the current defense planning environment, and other similarly uncertain, complex policy areas.

## 3. METHODOLOGY OF THE HIMAX PROCESS

The methodological description of the HIMAX process presented in this chapter is the core of this dissertation for two reasons. First, it explains how to apply the HIMAX process to a complex policy problem. Second, it provides structure for the rest of the dissertation by laying out the organization of a HIMAX analysis. The process of applying the HIMAX approach to a specific policy problem involves six distinct phases: preparation, generation, evaluation, prioritization, exploration, and interaction. Figure 3.1 shows the sequencing of these six phases, which are each described in detail in a section of this chapter.

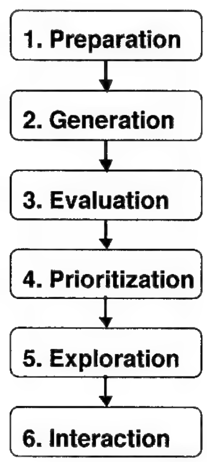



**Figure 3.1. The Six-Phase HIMAX Process**

Why is the HIMAX process structured this way? The first three phases in this sequence reflect the usual steps in a MADM analysis: the decision model is designed at the outset, and its parameters are determined; next, the options are selected and characterized; and then the options are evaluated and compared. The last three phases in the HIMAX process are extensions of this basic MADM approach. In the prioritization phase, the options are screened and compared using a few simple non-compensatory techniques. A parameterized strategic value function is then applied to the options, allowing preferences between them

to be compared visually. Strategic value scores are calculated for a few scenarios —specific combinations of parameter values that represent different types of futures—which are compared to cost estimates, if they are available. The exploration phase examines the impact of perturbations in the model parameters, which are derived from expert inputs, and alterations in the composition of the force options. Large perturbations examine the implications of minority opinions that have a substantial impact, and thus might yield useful insights. In the final interaction phase of the HIMAX process (which is not demonstrated in this analysis), the experts can revise their assessments and suggest changes in the options, after being shown a summary of the preliminary results. Once these changes have been made, the process is repeated to obtain the final results.

Before describing the details of the HIMAX process, it is important to point out that this particular method is not necessarily the best or the only way to apply exploratory modeling to MADM. While the sequential organization is a logical approach, the details of each phase are not necessarily optimal, so they could be altered to improve or refocus the process. In fact, the HIMAX process must be customized to a certain extent for each type of problem it is applied to. This customization delineates the dimensions of the evaluation model, which determine the types of expert inputs are collected in the preparation phase, and the specific calculations that are conducted in the rest of the process. The only structural features of the HIMAX process that must be customized are those that incorporate non-linearity. Dividing option components into different categories, each with their own separate set of characteristics, determines what types of synergistic interactions can be captured by the model. Role assignments within a class of components, if they are required, also affect how the characteristics of these individual entities are aggregated to the force level for each option. One other aspect of the HIMAX process is affected indirectly by customization; the scheme used to parameterize the strategic weights in the prioritization phase must obviously be changed to accommodate the customized set of missions. The

details of how the HIMAX process is customized are discussed in the following section, which describes the initial preparation phase.

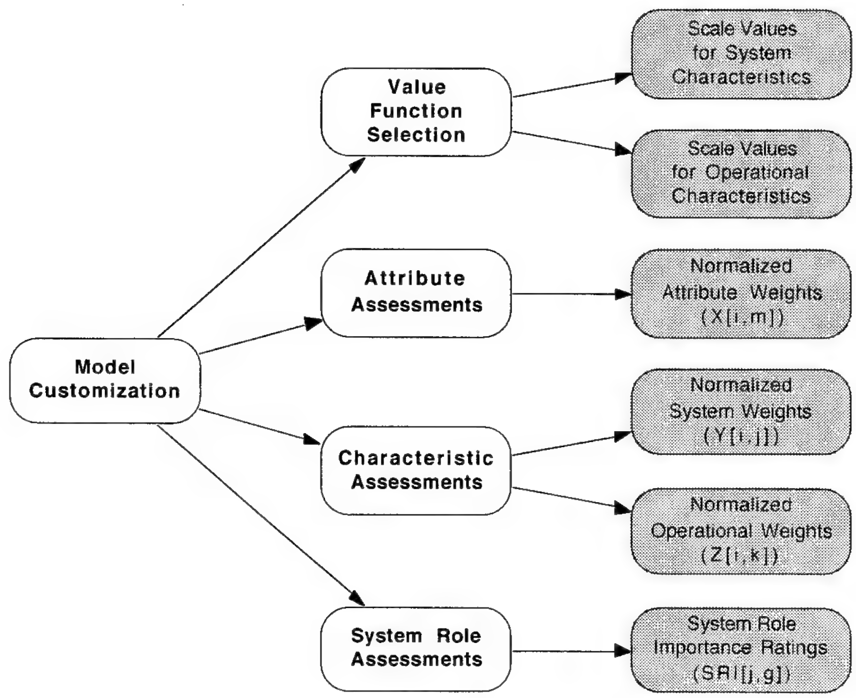



**Figure 3.2. The Preparation Phase**

## 3.1 PHASE ONE: PREPARATION

This initial stage of the HIMAX process consists of five tasks. First, the evaluation model must be customized for the problem under consideration; in this case, the evaluation of future military force options. This involves choosing and defining the missions, attributes, characteristics, and roles that delineate the dimensions of the evaluation problem. After the model is customized, its parameters are determined from inputs based on the responses of the experts participating in the analysis. First, a value function is selected for the rating scale of each characteristic. (In this particular problem, the options are composed of two types of components, system and operational, which are each rated on a

different set of characteristics.) These value functions map the integers of an ordinal rating scale—each level of a characteristic's rating scale is carefully defined for that specific characteristic—onto a continuous value scale. The experts then rate the importance of all the attributes relative to one another for each mission. They also rate the contributions that the system and operational characteristics make, individually and in combination, to each attribute. Finally, they rate the importance of all the system characteristics in each role that a system can play. The evaluation model uses the median response among all the experts as the inputs to the model for all three sets of ratings. Figure 3.2 depicts the relationships between these five tasks; customization precedes value function selection, and the assessment of attribute, characteristic, and system role ratings. The characteristic and attribute ratings determine the normalized weights used to calculate force effectiveness, while the system role ratings enable the model to aggregate the characteristics of each force option based on its composition.

## Model Customization

The structure of the HIMAX evaluation model is customized for the type of problem under consideration here—evaluating future ground force options—by selecting and defining its four key dimensions:

*Missions.* In the HIMAX framework, the effectiveness of each option is evaluated for a number of different missions, which represent various situations or circumstances in which an option might be used. In the evaluation of ground force options, these missions are exactly that—military missions that a force could be called upon to perform. The set of missions (indexed by m) selected for an analysis of this type should span a wide range of operations, encompassing all those that are likely to occur or are especially important.

*Attributes.* The essential properties of an option are represented by a set of attributes (indexed by i), which are related to a hierarchy of objectives that links them to an overarching goal (Saaty, 1980). In this case, the attributes represent

the essential properties of a ground-attack force, and are linked to a set of broad future capability objectives. The evaluation model calculates the attribute levels of each force option based on its composition and its components' properties. Thus, attributes do not have their own rating scales; instead, they use continuous 1-to-9 scales derived from the scales used to rate component characteristics.

*Characteristics.* The components of an option—systems and operational concepts in this case—may have essential properties that are somewhat different from those of the force as a whole. Component-level properties are represented in this analysis by two set of characteristics: system characteristics (indexed by j), and operational characteristics (indexed by k). A discrete 1-to-9 ordinal rating scale is defined for every characteristic; these definitions specify the meaning of each of the nine integer scale levels. Drawing a distinction between attributes at the force-level and characteristics at the component-level is important because it allows every system and operational characteristic to contribute, individually and in combination, to every attribute. This bottom-up approach captures some of the innate complexity in the performance of an interdependent military force.

*System Roles.* The components of an option may play quite different roles, depending on their function and capabilities. In evaluating force options, it is assumed that only the system components of an option (i.e., vehicles, aircraft and infantry teams) can play different roles. Some systems, for example, may engage in reconnaissance, while others provide indirect fires. Each role emphasizes or requires some characteristics more than others, so assigning a role to each system allows its characteristics to be weighted accordingly when the characteristics of the force as whole are calculated. This enables the system components of an option to complement one another by contributing more to the characteristics that their role focuses on, and less to those that it does not emphasize. (The operational concepts used by a force, however, do not play different roles. They are simply employed to a greater or lesser extent, depending on circumstances; they do not compensate for each other's weaknesses like system components do.)

The set of system roles (indexed by g) defined for this type of analysis should encompass all of the different roles that a system can play in a ground force.

Each of these four sets should be as complete, operational, decomposable, non-redundant, and minimal as possible.[9] To be complete, a set must include every important aspect of the problem, encompassing all the relevant objectives and considerations. A set is operational if it can be used meaningfully by the expert assessors, and is sufficiently transparent for decision-makers to use it. A set is decomposable if it breaks down the problem into small, manageable pieces. A set will avoid confusion and double-counting if it is non-redundant—i.e., all of its members are mutually exclusive. Lastly, but importantly, a set is minimal if it is as small as possible, within the constraints imposed by the other four criteria. To the extent that the sets achieve these goals, the evaluation model will be more comprehensible and more reliable, and thus more useful for policy applications.

### Value Function Selection

Based on input from the participating experts, a functional form is selected for the value function associated with each system and operational characteristic. These functions map every level of a characteristic's nine-point rating scale to a value that indicates its relative importance on a continuous 1-to-9 scale.[10] The experts select a function for each characteristic from among the five standard value functions shown in Table 3.1, which are depicted in Figure 3.3. Also, if they do not feel that any of the standard functions are appropriate, they can define and use a custom option. The experts are instructed to choose the function

--------

[9] These five "desirable properties of a set of attributes" were proposed Keeney and Raiffa (1993; pp. 50-53).

[10] The value functions are pegged, so they must map rating levels 1 and 9 to 1 and 9 on the continuous scale. All other levels must be mapped to values between 1 and 9 (inclusive). These requirements ensure that the resulting characteristics values stay in the 1-to-9 range, and match with the underlying ratings at the upper and lower extremes of this range. The value functions should also be monotonic, mapping each level to a value greater than or equal to the value that the level immediately below it is mapped to.

that best reflects the true differences in value between the scale levels, thus correcting for any bias in the way the scale has been specified. For instance, an expert should select the linear function if he feels that the levels of a characteristic's rating scale are equally spaced (i.e., there is no bias), while he should select the concave function if he feels that the difference in value between adjacent levels is greatest at the low end and decreases moving up the scale. If, as is likely, all the participating experts do not pick the same function for a characteristic, then the most common selection is used in the model.[11] The other selections are noted, however, so that the impact of using them instead can be explored later.

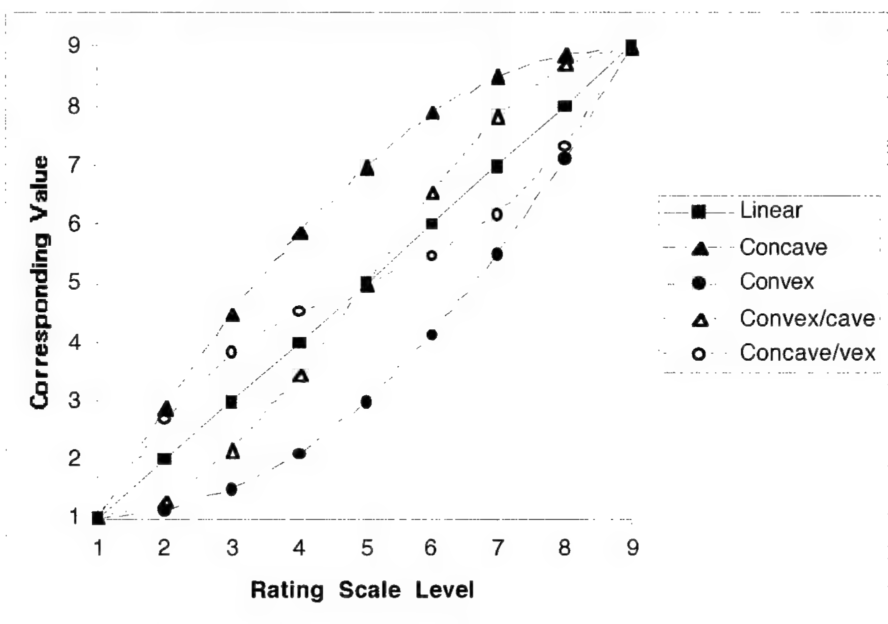



**Figure 3.3. Standard Value Function Options**

---

[11] If there is a tie, where the same number of experts select the most popular choices, it is broken by comparing the leading functions to the selections made by each of the other experts, who did not pick any of them, to determine which one they would prefer. For example, if there are five experts and two pick linear, two others pick concave, and the fifth picks convex, then the linear function will be used because the expert who picked convex would presumably prefer linear over concave, since it is the closer of the two leading choices to the function he selected.

**Table 3.1**

**Standard Value Function Options**

| Scale Level | Linear | Concave | Convex | Convex/cave | Concave/vex |
|---|---|---|---|---|---|
| 1 | 1.000 | 1.000 | 1.000 | 1.000 | 1.000 |
| 2 | 2.000 | 2.875 | 1.125 | 1.304 | 2.696 |
| 3 | 3.000 | 4.500 | 1.500 | 2.172 | 3.828 |
| 4 | 4.000 | 5.875 | 2.125 | 3.469 | 4.531 |
| 5 | 5.000 | 7.000 | 3.000 | 5.000 | 5.000 |
| 6 | 6.000 | 7.875 | 4.125 | 6.531 | 5.469 |
| 7 | 7.000 | 8.500 | 5.500 | 7.828 | 6.172 |
| 8 | 8.000 | 8.875 | 7.125 | 8.696 | 7.304 |
| 9 | 9.000 | 9.000 | 9.000 | 9.000 | 9.000 |

### Attribute Assessments

The normalized attribute weights (X[i,m]) are derived from the experts' ratings of the importance of each attribute (i) as compared to every other attribute (l), within the context of a particular mission (m). They use the scale shown in Table 3.2 for these ratings.[12] Each attribute only has to be compared to every other attribute once, since the comparisons are assumed to be symmetric; the rating of one attribute with respect to another is the reciprocal of the opposite rating (i.e., r[i,l,m] = 1/r[l,i,m]), and the rating of an attribute compared to itself is unity (i.e., r[i,i,m] = 1). Thus, if there are a total of L attributes, then only L(L–1)/2 pair-wise assessments per mission are needed to determine the entire attribute rating matrix.[13] The values used in the model for these attribute ratings (r[i,l,m]), are determined by finding the median response among the experts for

---------

[12] This is the standard AHP scale used by Saaty (1980) and many others. It encompasses the full range of qualitative distinctions that, according to Saaty (1980), people can reasonably be expected to make, and is within the psychological limit of 7±2 described by Miller (1956).

[13] The number of unique combinations of two different attributes from among a set of L attributes is L!/(2!·(L-2)!), which is equivalent to L(L-1)/2. This is the number of elements in the upper right (or lower left) portion of an LxL matrix, not including the diagonal elements.

each comparison[14], and then filling in the opposite corner of the matrix for each mission with their reciprocals (and placing 1s on the diagonals).

**Table 3.2**

**Rating Scale Used to Assess the Importance of One Attribute (i) Relative to Another (l) for a Specified Mission (m)**

| Rating | Relative Importance "i is ___ important than l" |
|---|---|
| 1/9 | extremely strongly less |
| 1/8 | . |
| 1/7 | very strongly less |
| 1/6 | . |
| 1/5 | strongly less |
| 1/4 | . |
| 1/3 | moderately less |
| 1/2 | . |
| 1 | equally as |
| 2 | . |
| 3 | moderately more |
| 4 | . |
| 5 | strongly more |
| 6 | . |
| 7 | very strongly more |
| 8 | . |
| 9 | extremely strongly more |

The attribute weights for each mission are then calculated using the eigenvector normalization process (Saaty, 1980). The first step of this process is to calculate the geometric mean (x[i,m]) of the ratings for each attribute relative to every other:

$$x[i,m] = \left(\prod_{l=1}^{L} r[i,l,m]\right)^{1/L}. \tag{3.1}$$

--------

[14] As with the other expert assessments, if the number of responses is even, the evaluation model uses the lower of the two middle ratings. Because of the symmetry of the attribute ratings matrix, however, this approach introduces a systematic bias, which is based on the order in which the attributes are placed in the matrix. An alternative approach that would remove this bias would be to use the geometric mean of the experts' responses instead. This, however, would yield non-integer ratings, thereby making ±1 excursions aimed at exploring the impact of small rating errors less meaningful.

Next, the attribute weights for each mission, X[i,m], are computed by normalizing the geometric means across all attributes:

$$X[i,m] = \frac{x[i,m]}{\sum_{i=1}^{L} x[i,m]}. \tag{3.2}$$

These calculations yield a different set of attribute weights for each mission, thus allowing the same force option to have different levels of effectiveness for each mission. This approach goes beyond traditional AHP applications (Zahedi, 1986) because it uses different weights to evaluate the same attributes in different situations, rather than relying on a single set of attribute assessments that implicitly averages across all possible circumstances. In the prioritization phase, the HIMAX process also has the flexibility to consider different futures, in which the importance or likelihood of the various missions can vary.

**Table 3.3**

**Rating Scale Used to Assess the Importance of System Roles, and of the Contributions that Characteristics Make to Force Attributes**

| Rating | Degree of Importance |
|---|---|
| 0 | none |
| 1 | minimal |
| 2 | . |
| 3 | moderate |
| 4 | . |
| 5 | strong |
| 6 | . |
| 7 | very strong |
| 8 | . |
| 9 | extremely strong |

## Characteristic Assessments

The evaluation model weights each system and operational characteristic to indicate how large a contribution it makes to each force attribute. These weights are derived from a series of assessments made by the experts using the 0-to-9 scale shown in Table 3.3. The experts assess the "main effect" contribution of

each system and operational characteristic, as well as "synergistic" contributions due to first-order interactions between system and operational characteristics.[15] The main effect contributions represent the direct, independent effect of a single system or operational characteristic. The synergistic contributions represent the extra effect of interactions between an operational and a system characteristic, over and above their individual main effect contributions.

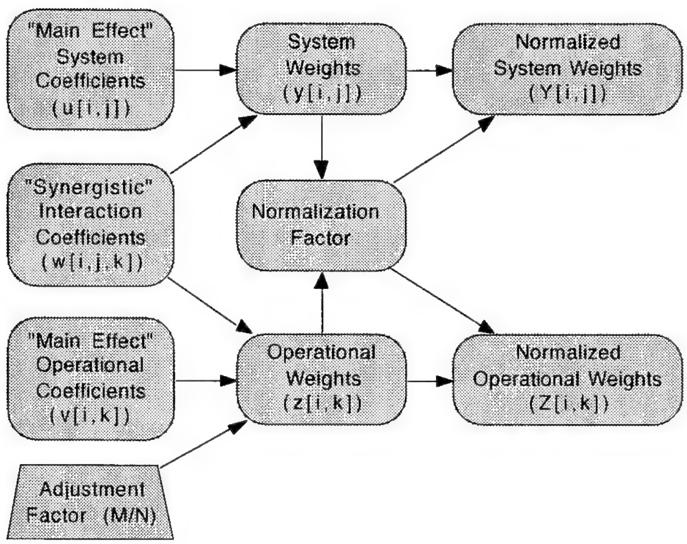



**Figure 3.4. Calculation of Normalized Characteristic Weights**

The values of the system and operational main effect ratings (u[i,j] and v[i,k], respectively) and the synergistic ratings (w[i,j,k]) used by the evaluation model are determined by finding the median of the experts' responses for each rating.[16] Figure 3.4 illustrates how the model combines these three sets of ratings

---

[15] Only synergistic interactions between one system characteristic and one operational characteristic are considered. Thus, if there are M system characteristics and N operational characteristics, then each expert is asked to make a total of M·N such assessments. Interactions between two characteristics of the same type, system or operational, are not considered, nor are interactions among three or more characteristics of any type.

[16] If there is an even number of responses, the lower of the two middle ratings is used, rather than their mean, since the rating used by the evaluation model must be an integer. For example, if the four responses for a certain rating are 2, 3, 4, and 6, then the model will use a

to calculate two sets of normalized weights (Y[i,j] and Z[i,k]), which indicate how important each system and operational characteristic (j and k, respectively) is for every attribute (i).

These weights act as exponents on their respective characteristics before they are multiplied together to calculate the attribute levels of an option—i.e., attribute = $\prod$ (characteristic$^{weight}$). The model uses this weighted product method (WPM)[17], rather than a conventional simple additive weights (SAW) approach[18], because of its built-in bias against options with unbalanced characteristics. For example, if an option has only two characteristics, with values of 2 and 8, that are given weights for a certain attribute of 0.75 and 0.25, respectively, then the SAW approach would yield an attribute value of 3.5, but the value would only be 2.83 using the WPM. If, however, the two characteristics each had a value of 3.5, then both techniques would give the attribute the same value (3.5), independent of the weights. In effect, the WPM places more emphasis on the characteristics of an option that have relatively low ratings, and less on those with higher ratings. This conservative slant is especially justified in this particular application because it reflects two important and enduring features of armed conflict: an intelligent opponent will tend to exploit your weaknesses and avoid your strengths; and the inherent confusion and uncertainty of war will tend to expose your weaknesses and diminish your strengths.[19]

The normalized weights, Y[i,j] and Z[i,k], include contributions from their respective characteristics, and from synergistic interactions between them and each characteristics of the other type. These weight calculations incorporate an

---

value of 3 for this rating, even though the median is 3.5. This approach is used because it ensures that the rating used by the model was given by at least one of the experts.

[17] According to Yoon and Hwang (1995; p. 37), the WPM was introduced by Bridgeman (1922), but is not widely used, even though it "possesses sound logic and a simple computational process."

[18] The weights are multipliers in a linear calculation: attribute = $\sum$ (weight · characteristic)

[19] Clausewitz (1976) referred to this tendency as "friction."

important constraint: given equal ratings, the contributions from the three sources—direct system and operational contributions, and synergistic interaction effects—must be exactly equal (1/3 each). To meet this constraint, each synergistic contribution is split equally between the two characteristics involved, and then averaged across all characteristics of the other type. An adjustment factor is also applied to correct for any difference there may be in the number of system and operational characteristics.

Raw values of the weights for each characteristic are calculated first, and then normalized to obtain Y[i,j] and Z[i,k]. The interaction terms in the weighted product use the geometric mean (i.e., the square root of the product) of the two characteristic values to give each characteristic involved an equal contribution. So, for each characteristic weight, the interaction ratings are simply divided by two, averaged across all characteristics of the other type, and then added to the main effect rating.[20] The raw system characteristic weights (y[i,j]) can, therefore, be calculated as follows:

$$y[i,j] = u[i,j] + \frac{1}{N} \cdot \sum_{k=1}^{N} w[i,j,k]/2, \tag{3.3}$$

where N is the total number of operational characteristics. Similarly, the raw operational characteristic weights (z[i,k]) are calculated as follows:

$$z[i,k] = \frac{M}{N}\left(v[i,k] + \frac{1}{M} \cdot \sum_{j=1}^{M} w[i,j,k]/2\right), \tag{3.4}$$

where M is the total number of system characteristics. The adjustment factor, M/N, is included to ensure that contributions made by system and operational

--------

[20] Since the model uses the WPM, the exponents on each characteristic can be summed. Each synergistic interaction term is of the form $(B \cdot C)^{w/2}$, or $B^{w/2} \cdot C^{w/2}$, where B is a system characteristic, C is an operational characteristic, and w is the rating of their interaction. So, it makes a contribution of w/2 to the exponent of each characteristic.

characteristics are counted equally.[21] Each raw characteristic weight is then divided by the sum of all the raw weights (both system and operational) for the appropriate attribute. The resulting normalized weights for the system and operational characteristics, Y[i,j] and Z[i,k], respectively, are thus given by:

$$Y[i,j] = \frac{y[i,j]}{\sum_{j=1}^{M} y[i,j] + \sum_{k=1}^{N} z[i,k]}, \quad \text{and} \quad Z[i,k] = \frac{z[i,k]}{\sum_{j=1}^{M} y[i,j] + \sum_{k=1}^{N} z[i,k]}. \qquad (3.5)$$

## System Role Assessments

Next, the experts rate the importance of every system characteristic (i) for each possible role (g) that a system could play in a force. For these ratings of system role importance they use the 0-to-9 scale in Table 3.2, the same one they use for the characteristic assessments. Similarly, the model uses the median response among the experts for each system role importance rating (SRI[j,g]).[22] These ratings determine the characteristics of each force by indicating how the characteristics of its component systems should be weighted according to the role they play. This approach permits the components of a force to complement each other by playing roles that emphasize their strengths and downplay their weaknesses. For example, a long-range missile system, which has lots of firepower but not very much protection, would be used most effectively in a role where firepower is much more important than protection. In such a role, this system would contribute more to the firepower of the force, and take away less from its protection, out of proportion to its numbers in the force.

---

[21] The adjustment factor M/N removes a bias that would favor the set of characteristics with more members (i.e., system or operational), resulting in disproportionately large weights for those characteristics relative to the others.

[22] As with the characteristic ratings, if there are an even number of responses, the model uses the lower of the two middle ratings, not their mean (which is the true median).

## 3.2 PHASE TWO: GENERATION

In this phase of the HIMAX process, force options are constructed in three steps, as shown in Figure 3.5. First, the indexes that define the options and their components are named. Next, the exact composition of each option is specified. Finally, the expected performance of the force components are characterized, and then used to determine the force-level characteristics of each option.

### Component Definitions

The first step in the generation phase is to define three sets of index arrays that give names to: the force options being considered (f), the complete set of all component systems that comprise these options (s), and the operational concepts that guide how the systems in a force are used (t). Together, these three arrays delimit the complete space of potential options. The options considered only represent a few specific points in this space, but the framework that it provides is used in the exploration phase, where slightly modified versions of the options are evaluated and compared.

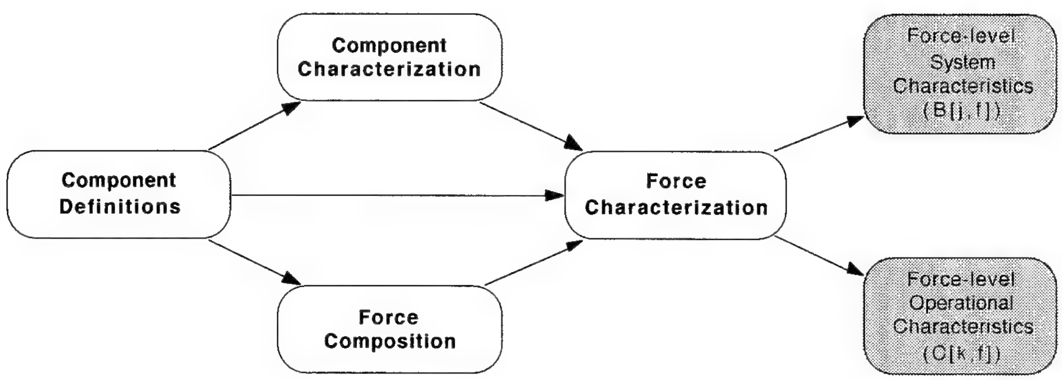



**Figure 3.5. The Generation Phase**

### Force Composition

The HIMAX process can be used to compare several force options at a time, provided that they are all sufficiently distinct from one another. These options can differ in size and composition, but should be similar in terms of their

organizational scope (e.g., a U.S. Army brigade), the amount of ground they can influence or control (e.g., 100 $km^2$), and how they would be used (as an independent combined-arms team). An option is constructed by indicating its system and operational composition, which are used to calculate its force-level characteristics, as depicted in Figure 3.5.

The system composition of an option is specified by an array indicating the number of systems of each type in the force (NSF[s,f]).[23] A corresponding array of quantity weights (q[s,f]) is then derived by calculating the proportion of the whole force that each type of system comprises:

$$q[s,f] = \frac{NSF[s,f]}{\sum_{s=1}^{S} NSF[s,f]}, \tag{3.6}$$

where S is the total number of system types in all of the options. For example, an option consisting of two systems, with 30 of one and 20 of another, would have quantity weights of 0.6 and 0.4, respectively.

These quantity weights are combined with importance weights derived from the appropriate role ratings for each component system, as depicted in Figure 3.6, to determine the overall importance weights used to aggregate the characteristics of the individual component systems. A single role is assigned to each type of system, based on its design and function, and the corresponding role numbers are indicated in a vector of system role assignments (SRA[s]). For each option, an array (p[j,s]) is constructed that indicates how important each characteristic is for every system, using the SRI[j,g] ratings associated with its assigned role (i.e., where g = SRA[s]):

$$p[j,s] = SRI[j, SRA[s]]. \tag{3.7}$$

---

[23] Smaller systems, such as infantry teams, should be counted in groups that are roughly equivalent to a vehicle, in terms of organization and behavior.

These importance ratings are then used to alter the quantity weights (q[s,f]) to account for the roles played by each system, yielding a somewhat different set of importance weights (bw[j,s,f]) for each system characteristic:[24]

$$bw[j,s,f] = \frac{p[j,s]\cdot q[s,f]}{\sum_{s=1}^{S}\left(p[j,s]\cdot q[s,f]\right)}. \qquad (3.8)$$

Finally, concept weights (cw[t,f]) are assigned to each operational concept (t) for every force option (f). These weights represent the proportion of time that the force uses a concept, or simply its relative importance. They are positive numbers, and must sum to 1 for each option.[25] So, if an option uses only one concept, its weight is 1 and all the others' weights are 0.

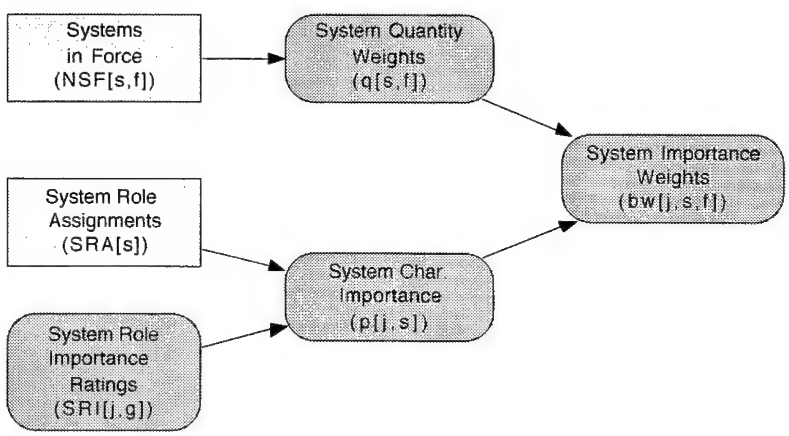



**Figure 3.6. Calculation of System Importance Weights Based on System Composition**

---

[24] Tavana and Banerjee (1995) use this normalized product formulation, which was introduced by Zeleny (1982), to combine intrinsic and subjective weights to calculate "overall importance" weights in a strategic decision model.

[25] A more complex algorithm, similar to the one used to determine the system weights (bw[s,f]), could be used to calculate the values of cw[t,f]. This simpler direct estimation approach is used, however, because this analysis only uses a few operational concepts.

## Component and Force Characterization

There are two stages in this second step of the generation phase: first, all of the force components are characterized individually; then, the characteristics of each option are aggregated to the force level. The anticipated performance of each system and operational concept may vary somewhat under the influence of technological and environmental factors. To capture this uncertainty, the model uses a simple discrete probability distribution for the characteristic ratings of each system and concept. In each case, the distribution includes three adjacent levels on the discrete nine-point scale specifically defined for that characteristic. So for each rating, this distribution is indicated by the median rating level, the probability of being one level higher, and the probability of being one lower. For example, if the median rating of a certain characteristic is 5, and the lower and higher probabilities are 0.2 and 0.1, respectively, then the probability distribution for that characteristic is: P(4)=0.2, P(5)=0.7, P(6)=0.1.

The ratings of each component's system and operational characteristics (br[j,s] and cr[k,t], respectively) are converted to their corresponding values (bv[j,s] and cv[k,t]) using the value functions selected in the preparation phase. The force-level system characteristics (B[j,f]) are then calculated using the WPM:

$$B[j,f] = \prod_{s=1}^{S} bv[j,s]^{bw[j,s,f]}. \qquad (3.9)$$

Similarly, the force-level operational characteristics (C[k,f]) are given by:

$$C[k,f] = \prod_{t=1}^{T} cv[k,t]^{cw[t,f]}, \qquad (3.10)$$

where T is the total number of operational concepts used by any of the options. These force-level characteristics are probability distributions, not merely point values, since they are calculated from the uncertain component characteristics.

## 3.3 PHASE THREE: EVALUATION

The two-stage evaluation model at the core of the HIMAX process is depicted in Figure 3.7. In the first stage, a contribution function combines the system and operational characteristics of each force option to determine its attribute levels. In the next stage, an effectiveness function weights these attributes differently for each mission to calculate every option's effectiveness. The options are then ranked, and specific pairs of options are compared to one another, based on their mission effectiveness.

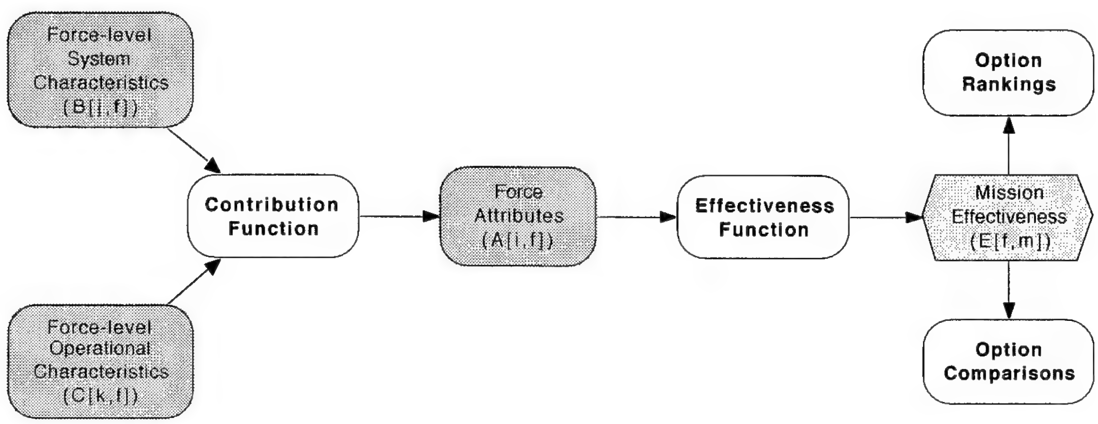



**Figure 3.7. Two-Stage HIMAX Evaluation Model, with Option Rankings and Comparisons**

### Contribution Function

The contribution function employs the WPM to combine the force-level characteristics of each force option—as derived from the characteristics of the system and operational concepts that comprise them—to determine their attributes. As described earlier, this approach allows the direct contributions of each characteristic to be merged with the effects of synergistic interactions between system and operational characteristics. In the following calculation of the attributes of each force option (A[i,f]), the normalized system and operational weights (Y[i,j] and Z[i,k], respectively) are exponents on the force-level system and operational characteristic values (B[j,f] and C[k,f], respectively):

$$A[i,f] = \prod_{j=1}^{M} B[j,f]^{Y[i,j]} \cdot \prod_{k=1}^{N} C[k,f]^{Z[i,k]}. \tag{3.11}$$

### Effectiveness Function

The second function in the evaluation phase calculates the effectiveness of each option (f) for every mission (m), using the WPM to weight its attributes. The normalized attribute weights (X[i,m]), which are different for each mission, are exponents on the attribute values (A[i,f]) in the product used to calculate the raw effectiveness ($e_{raw}$[f,m]) of each force option:

$$e_{raw}[f,m] = \prod_{i=1}^{L} A[i,f]^{X[i,m]}. \tag{3.12}$$

An opposing force is postulated for each mission and assigned an appropriate set of attribute values ($A_{opfor}$[i,m]), which are then used to calculate a meaningful floor level of effectiveness ($e_{floor}$[f,m]) for each mission:

$$e_{floor}[m] = \prod_{i=1}^{L} A_{opfor}[i,m]^{X[i,m]}. \tag{3.13}$$

A maximum effectiveness level ($e_{max}$[m]) for each mission is calculated using the attributes of a notional "positive ideal" option ($A_{ideal}$[i]) that combines the highest levels of every attribute exhibited by any of the force options being considered:[26]

$$e_{max}[m] = \prod_{i=1}^{L} A_{ideal}[i]^{X[i,m]}. \tag{3.14}$$

---

[26] Yoon and Hwang (1995) recommend this approach for use with the WPM. The positive ideal option, as defined here, is technologically plausible (though not necessarily feasible) because it is matched by at least one option on every attribute. This type of ideal option is an appropriate anchor point because utility is expected to decrease monotonically as the one moves away from it (Yu, 1985; Coombs, 1964, 1958).

These reference levels are used to adjust the effectiveness scale for each mission. The overall mission effectiveness (E[f,m]) of each option is then calculated by subtracting the floor effectiveness from the raw effectiveness of the option, and then dividing by the difference between the maximum and floor effectiveness:

$$E[f,m] = \frac{e_{raw}[f,m] - e_{floor}[m]}{e_{max}[m] - e_{floor}[m]}, \tag{3.15}$$

These effectiveness levels are, in fact, probability distributions, since they are calculated from uncertain option attributes (A[i,f]). To indicate the impact of this uncertainty, the median value of effectiveness is presented with error bars that indicate the 90% confidence interval (the $5^{th}$ and $95^{th}$ percentiles).

**Option Rankings and Comparisons**

The mission effectiveness results are compared across options in two different ways, both of which take advantage of the probabilistic nature of these outcomes. The first method simply ranks the options under consideration in each Monte Carlo run, and then sums up how often each option places in every position. The resulting rank frequencies are a direct indication of the impact that overlapping confidence intervals have on the effectiveness of options relative to one another in different missions. (The characteristics of the various options are correlated, since they include some of the same air systems and operational concepts, so the amount of overlap in mission effectiveness does not provide an accurate indication of option preferences.) During the exploration phase, these frequencies also act as baselines for measuring the impact of various changes.

The rank frequencies of all the options provide an overview of how the options fare relative to one another in each mission, but they do not always indicate how often one particular option is more effective than another, especially when more than two options are contesting the same position. This information is easily obtained by comparing the effectiveness of the two options in question in every run to compile a preference frequency for one option being

preferred to the other. These direct comparisons are useful because they involve key pairs of options, and provides a baseline for the strategic value comparisons in the prioritization phase.

## 3.4 PHASE FOUR: PRIORITIZATION

The force options under consideration are compared in this phase of the HIMAX process to determine which would be the most attractive under various circumstances. A variety of different methods could be used to prioritize the options based on their evaluation results. These include both compensatory scoring techniques, which permit the strength of an option in one mission to make up for its weakness in another, and non-compensatory approaches that do not allow such tradeoffs. The latter class of methods are employed first to identify options that are clearly inferior, or sort the options in a number of ways that could provide useful insights. Then, a simple compensatory score is used to measure each option's overall strategic value, based on specific assumptions about the relative importance of each mission. The impact of these assumptions on the preference frequencies for key option pairs is examined parametrically, and the results for the most interesting comparisons are presented visually.

### Option Screening

Before calculating a strategic value for every option, it may be helpful to first apply one or more of three different non-compensatory techniques: dominance, attitude-oriented ranking and sequential elimination. These techniques are easy to apply and can often provide quite useful insights. Dominance screening identifies options that are clearly inferior, and may not be worth considering further, independent of any particular set of mission preferences. Attitude-oriented methods, like maximin and maximax, highlight the merits of certain options across all possible missions. Finally, sequential elimination sorts options based solely on a strict ranking of the missions. The

remainder of this section, which discusses the specifics of how these techniques could be applied, draws heavily on Yoon and Hwang (1995).

*Dominance*. An option is eliminated when it is dominated by another option, provided that it is also inferior with regard to other important factors, such as cost. Simply put, an option is dominated if another option is equal or superior to it in every respect, and under all circumstances. Strict interpretation of this definition requires that every one of the dominated option's attribute values be less than or equal to the value of the corresponding attribute of the superior option. Whenever this condition is met, the alternative option will always be more effective than the dominated option, no matter how the attributes are weighted for any particular mission.[27]

*Attitude Orientation*. These methods require a perception of the strategic environment that warrants a certain attitude, the two most commonly used being pessimism and optimism. If the environment dictates pessimism, then the highly risk-averse maximin approach would be appropriate, since it identifies the option with the highest minimum level of effectiveness. This is a robust method because it emphasizes the worst-case possibility of having to use a force to perform the mission for which it is the least effective. By contrast, the optimistic maximax approach is much more aggressive: it picks out the option with the highest maximum effectiveness level. This method identifies highly specialized options that may not be very robust, but are relatively effective for only one particular mission.

*Sequential Elimination*. Options may also be eliminated based on their mission effectiveness results, provided that there exists a clear set of hierarchical relationships among the missions. The lexicographic elimination method can be

--------

[27] The dominance approach could be applied to mission effectiveness instead of the force attributes. This would make domination more likely, but the dominance relationships would be dependent on the specific attribute weights assigned to each mission. So, for this approach to be

applied if there is one mission that is clearly much more important than all the others, and there is a dominant mission among those remaining, and so on—i.e., the missions can be ranked in terms of general importance. This method ranks the options according to their effectiveness in the most important mission; if two or more options are tied, then their effectiveness in the next most important mission determines their rankings. Comparing the option ranking created in this simple manner to those determined using a more complex compensatory method may produce some useful insights.

### Strategic Value Comparisons

Unlike the non-compensatory methods described above, compensatory scoring incorporates mission preferences into a broad measure of overall value. The effectiveness levels of each force option can be aggregated across missions using either additive or multiplicative weights. Effectiveness itself is calculated using the WPM, which is multiplicative, because this approach accounts for the inevitable uncertainties and challenges of combat by systematically favoring balance over disparity. At the strategic level, however, decisions should be more even-handed, so a risk-averse bias is not appropriate. Thus, a SAW approach is used instead to calculate the strategic value (SV[f]) of each force option (f):

$$SV[f] = \sum_{m=1}^{TM} (SW[m] \cdot E[f,m]), \tag{3.16}$$

where SW[m] is the additive strategic weight associated with each mission (m).[28]

---

used properly, the mission effectiveness distributions would have to be expanded to include the effects of errors in the expert assessments used to calculate the attribute weights.

[28] Each of these weights represents the anticipated marginal strategic benefit of improving the mission effectiveness of a force option (dSV/dE), and is solely determined by the likelihood and importance of the mission (m). Thus, the impact of changing such a weight is independent of the mission effectiveness of the associated force option. A similar multiplicative weight, on the other hand, would really be an elasticity ((dSV/dE)·(E[f,m]/SV[f])), so its interpretation would have to take into account the baseline strategic value and effectiveness of the option.

These mission weights are highly uncertain because they are intended to capture and integrate the likelihood and strategic importance of each mission, which are both extremely difficult to predict. The probability that U.S. forces will be called upon to perform a particular mission, and the degree to which U.S. interests would be at stake in that mission, are clearly dependent on the nature of the security environment within the specified timeframe. Of course, trying to predict what the future will be like, even in very general terms, is always a major challenge.[29] Mission weights are, therefore, inherently uncertain because the future they are meant to represent is itself so uncertain. In light of this, it would be misleading to rely on a single "best guess" set of mission weights, even if they were based on sophisticated prognostication (Lempert et al., 1996). What really matters is how the strategic value rankings of the force options are affected by changes in the mix of mission weights, which reflect shifts in the future security environment. If the rankings are unaffected by plausible changes in these weights, then the inherent uncertainty is not so relevant. On the other hand, if the rankings are significantly altered when plausible changes are made, then the uncertainty is important and its implications should be examined more closely. This key issue is addressed by a parametric analysis.

The mission weights are parameterized in a manner that captures the most relevant mission uncertainties. This approach is best illustrated with a simple example. Suppose two options (1 and 2) are being compared, and there are three missions (A, B and C). Only two parameters are needed to represent the three mission weights, since their weights must sum to 1. The ratio between the weights on missions A and B is used as one parameter ($P_1 = w_A / w_B$), and the other parameter is defined as the ratio between the weight on mission C and the sum of the weights on missions A and B ($P_2 = w_C / (w_A + w_B) = w_C / (1 - w_C)$). The mission weights can be expressed in terms of these two parameters as follows:

--------

[29] A number of valiant attempts are included in Khalilzad and Lesser (1998).

$$w_A = \frac{P_1}{(1 + P_1)(1 + P_2)}; w_B = \frac{1}{(1 + P_1)(1 + P_2)}; w_C = \frac{P_2}{(1 + P_2)}. \qquad (3.17)$$

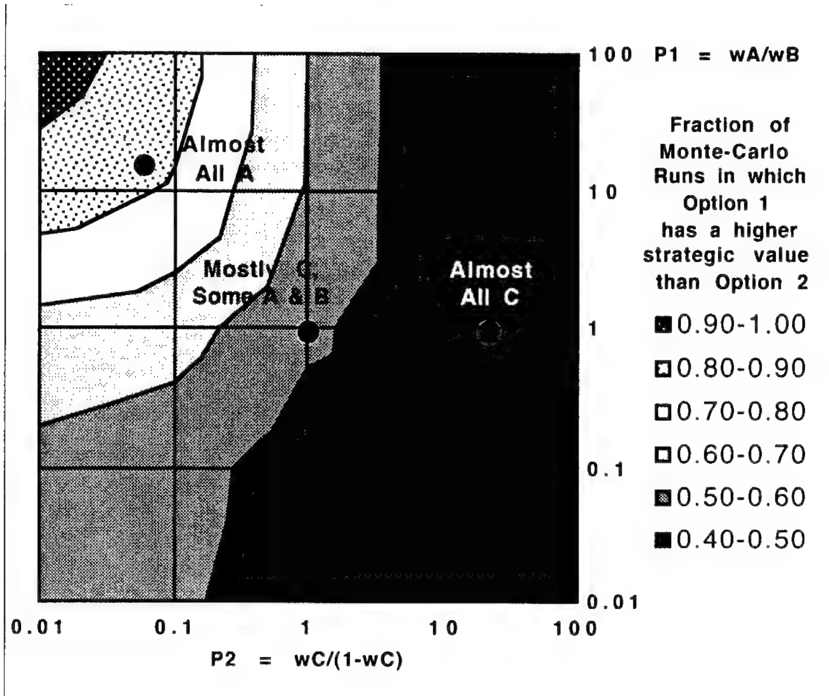



**Figure 3.8. Contour Plot of the Normalized Frequency of Option 1 Being Preferred to Option 2 As a Function of Two Parameters that Determine Strategic Mission Weights**

A contour plot like the one in Figure 3.8 can then be constructed to illustrate option preferences. The plot shows the fraction of all the Monte Carlo runs where the strategic value of option 1 is higher than that of option 2. This normalized frequency provides an estimate of how likely it is that option 1 will be preferred to option 2. Each point in this parameter space represents a different strategic environment, in which the corresponding mission weights indicate their relative importance in that type of future. In the example depicted by Figure 3.8, option 2 is slightly preferred to option 1 when $P_2$ is significantly greater than 1 (indicating that mission C is much more important than the other two missions). For lower values of $P_2$ (where mission C is less important), however, the value of $P_1$ comes into play; the larger $P_1$ is the more option 1 is preferred. In fact, when $P_1$ is very high (over 10) and $P_2$ is quite low (under 1/10),

(indicating that mission A is much more important than the other two missions), option 1 is clearly preferred to option 2, with normalized frequency values in excess of 0.8.

**Scenario Analysis**

Specific points or regions in this space can then be chosen to represent interesting future scenarios, as an aid to interpreting the results. The points associated with three such scenarios are shown in Figure 3.8: mostly C with some A and B; almost all C; and almost all A. In the first of these scenarios, the strategic weight on mission C is 0.5, and the weights on A and B are both 0.25. The remaining two scenarios both place most of the strategic weight, over 0.9, on one of the three missions, and very little weight on the other two. If, for example, missions A, B and C involved high-, medium- and low-intensity warfare, respectively, then the results could be interpreted as follows. In a future where low-intensity warfare is prominent, but other types of missions are also fairly important, though less likely (mostly C with some A and B), the two force options fare about the same, with option 1 having a very slight advantage. If, however, low-intensity missions are dominant (almost all C), option 2 would generally be preferred over option 1, but still not by that much. On the other hand, in a future where low intensity missions are not very prevalent, and high-intensity missions are the principal concern (almost all A), option 1 is clearly the better choice.

## 3.5 PHASE FIVE: EXPLORATION

This phase of the HIMAX process provides an opportunity to examine the impact of making various types of changes in the form of the evaluation model and its inputs. There are three aspects of this model that could be altered: its structure, the ratings that determine its parameters, and the composition of the force options that it evaluates.

The structure of the evaluation model is determined by the customization choices regarding: system and operational characteristics (j and k, respectively) and their associated scales; standard value functions for these characteristics; and sets of system roles (g), force attributes (i) and missions (m). None of these structural choices, which determine the dimensions and scope of the model, are revisited in the course of exploration; they mark out the "space" that can be explored, and thus can not actually be explored themselves. Moreover, keeping the model's structure fixed ensures that the ratings and other inputs it needs are consistent from expert to expert, throughout the HIMAX process.

However, the expert assessments made in the preparation phase, and the force representation choices made in the generation phase, can together provide a basis for exploration. The rating inputs derived from the expert assessments determine the topology of the force-effectiveness "terrain," while the composition of each force option identifies a specific location in that terrain. Thus, there are two types of exploration that can be conducted in this space: perturbations of expert assessments that affect the terrain, and alterations of the force options that shift them to new locations.

The impact that both types of exploration have on the effectiveness results are estimated using two sorts of measures: differential effect, and rank shifts. To assess the first measure, the baseline level of effectiveness is subtracted from the new post-change level to determine its deviation ($\Delta E[f,m]$). Then, the difference between the maximum and minimum $\Delta E[f,m]$ across all options[30] is averaged across all missions to get the average differential effect (ADE):

--------

[30] This "differential effect" represents the largest possible impact on any pair of options. This pair consists of the option that improved the most (or declined the least) and the one that improved the least (or declined the most); the difference in effectiveness between these two options will have changed more than that of any other pair. Example: Three options, A, B and C, have baseline effectiveness levels of 3, 4 and 5, respectively. After a perturbation they have levels of 2, 7, and 6, respectively. B–A went from +1 to +5, C–A went from +2 to +4, and C–B went from +1 to –1, so B–A experienced the greatest impact, with an increase of 4. The differential effect

$$\text{ADE} = \frac{\sum_{m=1}^{TM}\left(\max\{\Delta E[f,m],f\} - \min\{\Delta E[f,m],f\}\right)}{TM}, \tag{3.18}$$

where TM is the total number of missions. This deviation-based measure does not, however, provide direct information on how preferences among the options are affected. Exploratory changes shift the effectiveness distributions of each option, thereby changing the degree to which they overlap with one another (if at all). Since these distribution s may be correlated with each other, the impact of an exploratory change is best captured by shifts in the option rank frequencies (ΔRF[p,f,m]).[31] The absolute values of these rank shifts are summed over all ranks (p), divided by two to correct for double counting, and then averaged over all options (f) and all missions (m), as appropriate, to determine the second impact measure, the average rank shift sum (ARSS):

$$\text{ARSS} = \frac{\sum_{m=1}^{TM}\left(\sum_{f=1}^{F}\left(\sum_{p=1}^{F}\left|\Delta RF[p,f,m]\right| \Big/ 2\right) \Big/ F\right)}{TM}. \tag{3.19}$$

## Expert Assessment Perturbation

The participating experts select value functions, and assess the importance attributes for different missions, characteristic contributions to these attributes, and the importance of system characteristics in various roles. The parameters of the evaluation model are derived from these choices, which together capture the key operational relationships that link capability-based characteristics to a

---

yields exactly this result: the changes in A, B and C are –1, +3, and +1, respectively, so the difference between the largest and the smallest is +3 – (–1) = +4.

[31] The rank frequency simply counts how often (in the Monte Carlo runs) an option receives a given rank, based on its mission effectiveness, relative to all the other options. ΔRF[p,f,m] is the difference between this count in the baseline case and after an input change. For example, if there are three options and the rank frequencies (out of 100 runs) of one of these options shift from 60 in first place, 30 in second, and 10 in third, to 75 in first, 20 in second, and 5

performance-based measure of effectiveness. Thus, the impact that errors or discrepancies in these parameters have on effectiveness is, in essence, a gauge of the potential consequences of operational uncertainty. Each of the four types of inputs are perturbed to illustrate the sensitivity of the option effectiveness results to such deviations.

Based on their analytical knowledge and operational experience, the experts select value functions for each system and operational characteristic. While the value function that the experts selected most often for a characteristic is the one used in the baseline evaluation, interesting alternative selections are also considered in this phase. The set of exploratory excursions is limited to those alternative selections chosen by a substantial number of experts, plus any others that are of special interest.[32] Each such selection (or combination of them) is implemented, and the resulting impact on the option effectiveness results is calculated, in terms of its ADE and ARSS values.

Assessing the relative importance of force attributes for different missions requires the experts to make high-level operational judgements that account for differences in mission requirements. Perturbations in the composite ratings for a given mission (r[i,l,m]) will change the corresponding attribute weights (X[i,m]), thereby altering the effectiveness of the various force options for that mission, and possibly even affecting their rankings.[33] These attribute ratings, which use the 1/9-to-9 scale shown in Table 3.2, are subjected to two different types of

---

in third, then the ranks shifts are +15, –10 and –5 for the three ranks, respectively. Note that the number of positive shifts equals the number of negative shifts, since the number of runs is fixed.

[32] Ideally, the experts should provide a brief rationale for each of their selections, and should be even more specific if the define and select a custom value function. This information could then be used to determine which alternative selections deserve to be considered. This analysis, however, does not press this point, since it is merely a demonstration of the approach.

[33] The attribute ratings do not matter much for force options that are dominated; if an option has lower ratings on every attribute as compared to one of the other options, then its effectiveness will always be less than that of the other option, independent of the weights placed on each attribute. Attribute rating perturbations can, however, have a substantial impact on preferences among options that have overlapping effectiveness distributions.

perturbations: large, controversial changes that are constructed from the expert responses that are most different from the baseline ratings; and multiple, small perturbations, which combine the ±1 changes that have the most influence individually. In both cases, impact is measured by a version of the ARSS that averages across force options, but not missions, since perturbing an attribute rating for a particular mission only affects the option rankings for that mission.

The baseline ratings of characteristic contributions (u[i,j], v[i,k] and w[i,j,k]) and system role importance (SRI[j,g]), which use the 0-to-9 integer scale shown in Table 3.3, are also subjected to the same two types of perturbations. First, large changes are made in the most controversial ratings, then the impact of small changes in every rating are compared to find the ones that are most influential, which may then be combined together. Large, controversial perturbations shift one or a few ratings multiple levels, while small, influential perturbations only involve shifts of one scale interval in an interesting combination of ratings.

The large perturbations are constructed from the expert responses that differ from the baseline ratings the most, and are thus the most controversial, since they indicate a significant divergence in the opinions of the experts. Plausible combinations of these more extreme ratings are chosen and then applied to see which of them have the greatest impact on mission effectiveness, as measured by their ADE and ARSS values. The intent of this exploratory comparison is to distinguish the controversial characteristic and role rating disagreements that are most significant from those that are less consequential.

The marginal impact on effectiveness of perturbing each individual rating by ±1 is also calculated. Perturbing multiple ratings at the same time will, of course, have a more complex, and possibly more substantial impact on effectiveness. Therefore, a set of multiple ±1 perturbations, which involve only those individual ratings with the largest marginal effects, is constructed and then systematically explored to determine which combinations have the most impact.

The intent of this search is to reveal the combinations of characteristic and role ratings that, if rated slightly differently, would most influence the evaluation.

The combinations of roles, characteristics and attributes associated with these controversial and sensitive ratings, and the nature and magnitude of the effects caused by their perturbations, should generate useful insights into the types of operational misjudgments that would be the most misleading. If, for example, plausible changes to a couple of key ratings would cause an attractive force option to be significantly less effective in an important mission, then that option should be viewed with greater caution. On the other hand, if a similar set of changes caused a mediocre option to jump up in effectiveness across many important missions, then this option might be worth looking at more closely. In either case, of course, the new ratings must be both plausible and consistent as a set, such that a reasonable argument can be made to support them.

**Force Option Alteration**

The location of a force option can be altered by changing its composition (i.e., its system or operational components) in an attempt to find higher ground on the effectiveness terrain. System composition can be changed in four different ways: the relative proportions of constituent systems can be altered, current components can be removed, other systems can be added, and system role assignments can be changed. Similarly, operational composition can be altered by changing the proportions that indicate how often the force uses each concept.

The magnitude of these alterations is a subtle but important factor to consider. If the shift is incremental, involving only small changes in system numbers or concept proportions, then it is really just a modification of an existing option. On the other hand, more drastic dislocations caused by large changes in component proportions, the introduction, removal or change in role of a component system, or the use of a very different mix of operational concepts, create entirely new force options. Thus, force option alteration can follow two

paths: it can focus narrowly on local improvement by incrementally exploring the regions near existing options; or it can take a broader approach, introducing new force options that are substantially different from the existing options. The exploration phase focuses on the former, deferring non-incremental excursions to the interaction phase.

The principal challenge posed by local incremental alteration lies in deciding where and how to explore the vicinity of each option. In this analysis, the proportion of each system—including those that are not already in the force —is increased, while leaving the relative proportions of all the other systems the same. Similarly, the concept weights of each option are each increased while keeping the relative mix of the other concepts the same. These systematic alterations, in effect, explore the region near the option's initial location. Their impact, which is only measured by the ADE, provides an indication of the marginal effectiveness of each type of system or concept, and suggests which modifications are likely to improve effectiveness the most. Based on these results, a few other versions of each option are constructed that change the overall mix of systems or concepts, often altering more than one proportion at the same time. The impact of these custom alterations is measured using a version of the ARSS that is averaged over missions, but not force options, so that the impact on each option is shown separately. Since these alterations are designed to improve the option the affect, this option is generally the one that experiences the largest rank shifts, which are usually in its favor.

### 3.6 PHASE SIX: INTERACTION

The purpose of the interaction phase is to shed new light on relationships among component characteristics, option attributes and overall effectiveness, and then give the participating experts an opportunity to revise their initial assessments and suggest new or modified force options. This interaction is organized around exposure and feedback; the experts are be exposed to new

information that is relevant to the analysis, which acts as a stimulus, to which the experts' feedback is the response. This feedback could include revised choices and assessments, and possibly even suggestions for new options, that would then be incorporated into the final results of the analysis. The intent of this structured interaction is to generate new insights for the experts that enable them to provide improved assessments, and help them develop ideas for new force options that are better than the existing ones in some respects. In particular, it is hoped that the extra information will highlight synergistic effects that the experts may have neglected to consider initially. Overall, the feedback should improve the validity of the analysis, and increase confidence in its results.

The analysis used to demonstrate the HIMAX process in this dissertation, however, did not apply this phase of the process. It focused on the earlier phases, which rely more on the decision model at the core of the process, leaving the interaction phase to be developed more fully in future applications. This emphasis was driven by two factors: first, the limited resources available for this work precluded extensive interactions with the experts, who participated voluntarily and were not compensated for their time; and second, the intricacies of designing effective interaction procedures, which could include web-based interfaces, are substantively quite different from the decision modeling required to implement the other phases of the process. This turned out to be a wise choice because the resulting implementation of the HIMAX process in Analytica™, a significant and unique contribution of this dissertation on its own, benefited greatly from the extra time and attention that it received.

## 3.7 CONCLUDING REMARKS

This chapter described the six phases of the HIMAX methodology in detail, but also in quite general terms, providing a blueprint for applying this process to other appropriate policy areas. A principal purpose of this dissertation is to demonstrate the unique contributions of this methodology by applying it to a

complex, real-world policy problem. Thus, most of the remaining chapters (4–11) discuss how the HIMAX process was applied to a specific problem—the evaluation of future U.S. military force options—and interpret this analysis to illustrate how this process can yield useful insights and inform complex policy choices in an uncertain environment. Chapter 4 describes how the HIMAX process, especially its evaluation model, was customized to represent and assess military force options, with an emphasis on effectiveness in ground operations.

# 4. MODEL CUSTOMIZATION

This chapter describes how the decision model at the heart of the HIMAX process was customized to evaluate and compare the overall effectiveness of military force options for ground-oriented missions. This preliminary step in the preparation phase is critically important, and deserves its own chapter, because it forms a foundation for the rest of the analysis by determining what types of expert inputs are needed to derive the parameters of the evaluation model. (Chapter 6 describes the preparation phase.) Four sets of items were selected and defined to customize the HIMAX process for evaluating military force options:

- missions that a force may have to perform;
- attributes that represent the essential properties of a force;
- characteristics that capture the capabilities of the systems and operational concepts that comprise a force; and
- roles that component systems can play in a force.

The remainder of this chapter defines and discusses the missions, attributes, characteristics and system roles used in the analysis, which are listed in Table 4.1.

## 4.1 MISSIONS

This analysis uses a set of six representative missions: halt, defend, protect, evict, raid, and stabilize. Table 4.2 illustrates how these missions fit into current U.S. Army doctrine; the first three missions are defensive, while the second three are more offensive, and the third mission in each subset is also a type of peace operation.[34] These missions, which are defined below, vary considerably in both

--------

[34] U.S. Army doctrine treats most operations as being ether offensive or defensive in nature (U. S. Army, 1993). Peace operations can also be classified in this manner, but are

context and intensity, spanning a wide range of ground operations that U.S. forces might be expected to perform in the future.

**Table 4.1**

**Customized Sets of Missions, Attributes, Characteristics and System Roles**

| Missions | Characteristics | System Roles |
|---|---|---|
| Halt | *System* | 1. Direct Fire Attack |
| Defend | Transportability | 2. Direct Fire Support |
| Protect | Mobility | 3. Indirect Fire Close |
| Evict | Firepower | 4. Indirect Fire Far |
| Raid | Protection | 5. Close Air Support |
| Stabilize | Stealth | 6. Deep Air Interdiction |
| **Attributes** | Self-sufficiency | 7. Reconnaissance Scout |
| Deployability | *Operational* | 8. Reconnaissance Strike |
| Lethality | Awareness | 9. Special Operations |
| Maneuverability | Coordination | |
| Ability to Shock | Adaptability | |
| Survivability | Economy | |
| Sustainability | Ability to Support | |

*Halt.* Stall and weaken an enemy ground force that is attacking *en masse* over mixed or open terrain. A quick, potent response is required to halt the enemy force before it reaches its objectives. There is sufficient room for friendly forces to maneuver, either on the ground or by fire, and civilians are not mixed in with enemy forces, so this mission can be accomplished by a number of means, including long-range fires and rapidly-deployed mobile forces.

*Defend.* Deny use of, block access to, or seize and hold a critical area, such as an airfield or a port, for a limited amount of time (ranging from several hours to a few days) against a well-equipped enemy force until more potent reinforcements arrive. The rapid, flexible deployment of elite troops (e.g., light

---

increasingly treated somewhat differently. Here, the protect mission is a pre-emptive response aimed at creating peace, so it is defensively oriented, while the stabilize mission, which involves enforcing the peace after a conflict has ended, is proactive, and thus offensive in nature.

airborne infantry) and accurate, effective firepower are both likely to be essential for this type of mission.

**Table 4.2**

**Doctrinal Classification of Missions**

| | *Defensive* | *Offensive* |
|---|---|---|
| | Halt | Evict |
| | Defend | Raid |
| *Peace Operations* | Protect | Stabilize |

*Protect.* Prevent , obstruct or interfere with enemy operations against civilians and friendly forces—especially ethnic cleansing and counter-insurgency activities—in areas under the control of enemy forces. To accomplish this, enemy forces and infrastructures (supply, transportation, command and control, communications, etc.) must be attacked and disabled. Because enemy forces are intermingled with civilians, often intentionally, such attacks require extremely accurate and up-to-date intelligence to avoid (or at least minimize) civilian casualties. Persistent, reliable surveillance is also essential, as enemy forces will adapt their behavior (e.g., hide vehicles) and use deception (e.g., erect decoys) to reduce their vulnerability to attack.

*Evict.* Remove a dug-in and determined enemy force from a specified piece of territory. This requires a highly capable maneuver force with a significant ground presence. Substantial massed firepower, and sufficient time to plan and prepare for a coordinated attack, are preferred in this type of mission.

*Raid.* Surprise an enemy force while it is on the march or at rest in an effort to erode its strength, reduce its morale, and disrupt its organization. The intent of such missions is to create enough confusion to induce a total collapse, and thereby achieve a quick victory with fewer casualties. The ability to insert, hide and coordinate an effective attack, and then escape safely, is crucial. Reliable

intelligence and accurate discrimination are extremely important, especially if civilians are nearby, or are mixed in with the enemy forces.

*Stabilize*. Enter, occupy and control areas where hostilities have recently ended due to a successful invasion or a negotiated cease-fire. Disarm or escort away any troops, paramilitaries or local militias still in the area, separating rival groups where necessary. Respond rapidly and effectively to suppress armed resistance and outbreaks of civil violence. Maintain order and discourage theft, intimidation and retribution by providing rudimentary police services. Moderate levels of firepower, protection and mobility are needed to perform these tasks effectively, and the troops must be trained well to deftly handle the complex situations that will inevitably arise in this type of mission.

To further specify these definitions, two additional factors are associated with each mission: its time criticality, and the type of enemy force involved.[35] The time criticality of a mission, which is assigned one of three levels, provides an indication of its urgency and the amount of time available to prepare for it. A *low* level indicates that, while important, the mission is not especially urgent, and several weeks, or even a few months, are available for preparations. A *medium* level indicates that the mission is somewhat urgent, but several days, or even a few weeks, can be taken to prepare for it. A *high* level indicates that the mission is quite urgent, and must be performed on very short notice, with only a matter of days, or even hours, to prepare. Three different types of enemy force may be associated with a mission: a highly dispersed *light* force, consisting of non-elite dismounted infantry; a moderately dispersed *mechanized* force, with a mix of infantry and lightly armored vehicles, and a modest amount of firepower; and a highly concentrated *heavy* force, with mobile artillery, infantry fighting vehicles, and main battle tanks. Table 4.3 shows the time criticality of each mission, and

--------

[35] According to U.S. Army doctrine, these two factors should be considered, along with troop condition, terrain and weather, during the planning of any type of operation (U. S. Army, 1993).

the type of enemy force involved. (Appendix A describes the opposing forces considered for each mission in this analysis.)

**Table 4.3**
**Time Criticality and Type of Enemy Force Associated with Missions**

| Mission | Time Criticality | Type of Enemy Force |
|---|---|---|
| Halt | high | heavy |
| Defend | high | mechanized |
| Protect | medium | mechanized |
| Evict | low | heavy |
| Raid | high | mechanized |
| Stabilize | medium | light |

## 4.2 ATTRIBUTES

A somewhat different force may, of course, be better for each type of mission. To account for this, the evaluation model weights the various attributes of a force differently for each mission. The following six attributes represent the essential properties of a force in this analysis:

- Deployability: Ability to rapidly transfer the systems, crews, support personnel, supplies, equipment, and everything else the force needs to operate effectively, to, from and within the theater of operations.[36]
- Lethality: Ability to disable or destroy enemy forces reliably and efficiently.
- Maneuverability: Ability to move effectively on the battlefield to intentionally funnel, misdirect, engage, disengage or avoid enemy forces.
- Ability to Shock: Ability to concentrate firepower and exploit the resulting opportunities to surprise, delay, disrupt or demoralize enemy forces.

---

[36] Deployability is essentially the same as "strategic mobility."

- Survivability: Ability to avoid casualties, retain functionality and maintain organization while conducting operations, particularly when under attack.
- Sustainability: Ability to maintain effectiveness by having the supplies (food, fuel, ammunition, parts, medicine, etc.) and services (maintenance, transport, personnel, medical, etc.) needed to sustain offensive or defensive operations.

These attributes were chosen because they are related to four capabilities that will determine the overall effectiveness of U.S. ground forces in the future: *rapid response*, to deploy almost anywhere in the world within only a few days; *decisive impact*, to bring conflict to a swift, favorable conclusion; *minimal losses*, to avoid both allied and civilian casualties; and *limited dependence*, to minimize the amount of support needed to operate effectively.[37] Figure 4.1 shows the principal relationships between the force attributes and these broad capability objectives.[38] Three of the objectives are supported primarily by a single attribute; deployability enables rapid response, survivability reduces losses, and sustainability limits dependence. The three remaining attributes all contribute to the same capability objective: decisive impact. Lethality facilitates the direct destruction of enemy forces, while maneuverability enables a force to move effectively so it can better control the context and timing of its engagements with the enemy. The ability to shock allows a force to disrupt the enemy and exploit the resulting opportunities.

---

[37] REFERENCE TO AAN BRIEFING FROM WEB SITE.

[38] The links depicted in Figure 4.2 provide the primary rationale for why each attribute is included, but are not meant to preclude other relationships. For example, even though it can be argued that survivability indirectly facilitates decisive impact by enabling a force to maintain its strength and coherence during combat, this link is not shown in Figure 4.2 because the primary reason for including survivability is that it contributes to the minimization of losses.

These attributes are appropriate because they combine a number of the properties that are desirable in such a set.[39] This set is *complete, minimal* and *non-redundant*; it incorporates all of the important capability objectives for a future force, and consists of as few attributes as possible, all of which are quite distinct from one another. Also, there are only six attributes in the set, so there is no need for it to be *decomposable* it into smaller groups, since this total is within the range (7±2) that people can think about at one time (Miller, 1956). Most importantly, the attributes in this set are *operational*; they are all commonly used to describe the essential properties of ground forces, so they are meaningful for both military experts and political decision makers.

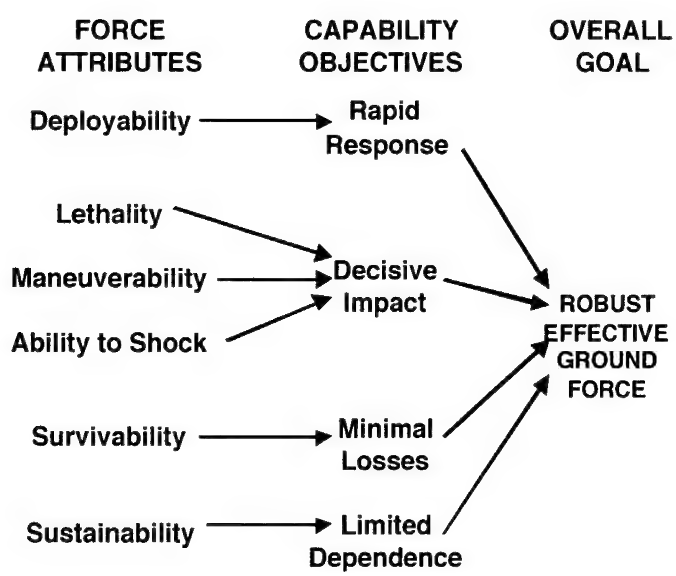



**Figure 4.1. Principal Relationships Among Force Attributes and Future Capability Objectives**

This set of attributes is used to assess the overall effectiveness of a force for each mission. The particular attribute levels of a force option are derived from the inherent characteristics of its components.[40] The following two sections

---

[39] These desirable properties, which were proposed by Keeney and Raiffa (1993), are discussed in more detail in the "Model Customization" section of Chapter 3.

[40] Since every characteristic can contribute to each attribute, two force options with very different characteristics can achieve the same level of a given attribute. For example, a high level

describe the specific system and operational characteristics used in this analysis, providing a definition for each, and discussing the important features of the nine-point scales used to rate them.

### 4.3 SYSTEM CHARACTERISTICS

Six characteristics, which are defined as follows, represent the key properties of component systems in this analysis:

- Transportability: Speed and ease with which system can be transported to, from and within the theater of operations, and then made ready for combat.
- Mobility: Ability of system to move effectively on the battlefield.
- Firepower: Ability of system to destroy or damage enemy systems in combat.
- Protection: Ability of system to avoid being destroyed or disabled by enemy fire, by reducing its likelihood of being hit when fired upon, and limiting the damage that it is likely to be incurred if it is hit.
- Stealth: Ability of system to avoid being engaged, by reducing its likelihood of being detected, recognized, tracked and targeted by enemy systems.
- Self-sufficiency: Extent to which system is not dependent on supplies, services and other support to maintain its essential capabilities during combat.

These characteristics are distinct from one another, and each one is an important determinant of at least one force attribute.[41] Transportability—a measure of how easy it is for a system to be moved over long distances—is a key factor in determining the deployability and maneuverability of a force. The next

---

of survivability can be attained solely through a great deal of protection (e.g., a network of bunkers), or through a mixture of protection, firepower and mobility (e.g., a group of tanks).

[41] While each characteristic is likely to be especially important for one or two attributes in particular, it may also contribute to other attributes as well. Thus, the model allows each system characteristic to contribute to every attribute, to the extent indicated by the expert inputs.

three members of this set, mobility, firepower, and protection, are the traditional characteristics used to assess the fighting value of armored vehicles (Simpkin, 1979; Ischebek and Spitzer, 1992). Mobility primarily enables maneuverability and shock, while firepower contributes greatly to both lethality and shock, and protection is obviously a major source of survivability. Stealth is an important counterpart of protection, encompassing those system properties that make it harder to find and attack, and thus also contributing to survivability. Self-sufficiency is a measure of how independent a system is of all types of support, so it is clearly a substantial contributor to sustainability.

A number of contributing factors are considered in determining how highly a system should be rated on the nine-point scale specified for each characteristic. Table 4.4 presents these factors, along with the proxies used to specify the characteristic rating scales. While the contributing factors are not always explicit in the proxy-based scales, which are shown in Table 4.5, they do highlight nuances in a characteristic's definition that can implicitly affect how a system is rated—an exceptionally high or low standing in a factor can justify a one notch increase or decrease in a system's rating.

**Table 4.4**

**Contributing Factors and Rating Scale Proxies for System Characteristics**

| Characteristic | Contributing Factors | Scale Proxies |
|---|---|---|
| Transportability | • *Design*. Mass, volume, dimensions and construction of system.<br>• *Essentials*. Crew, support personnel, specialized equipment and initial supplies (e.g., ammunition) needed to operate system in combat.<br>• *Preparations*. Tasks that must be performed after arrival, but before system can be used in combat (e.g., installation of appliqué armor). | • Weight of system (when in transit).<br>• Smallest platform system can be transported on.<br>• Ability of system to transport itself, or "self-deploy." |
| Mobility [a] | • *Operational mobility*. Moving to and from combat zones on main roads.<br>• *Tactical mobility*. Moving between engagements on minor roads and trails.<br>• *Battlefield mobility*. Agility in combat and versatility over rough ground. | • Maximum range of system (on main roads, between refueling stops).<br>• Typical top speed of system in combat. |

## Customization

| Characteristic | Contributing Factors | Scale Proxies |
|---|---|---|
| Firepower | • *Range*. Maximum distance from which targets can be hit.<br>• *Accuracy*. Probability of hitting target, given a single shot.<br>• *Effectiveness*. Probability of disabling target if it is hit.<br>• *Rate of fire*. Rate at which shots can be delivered on target. (Rate may be higher for short time periods, and lower for multiple targets.) | • Most lethal weapon on board system. |
| Protection | • *Directness*. Nature of protection technique; from less direct (typically active) techniques that reduce likelihood of a hit, to more direct (typically passive) mechanisms that reduce consequences of being hit.<br>• *Degree*. Extent of functions protected; from crew survival only (catastrophic), to key fighting capabilities (mobility and firepower), to full functionality.<br>• *Completeness*. Breadth of attack directions protected; from frontal arc only, to 360° horizontal coverage, to full hemispheric protection (including top-attack).<br>• *Reliability*. Likelihood that protection will function as intended; from dicey "hit or miss" methods, to stalwart techniques that almost always work.<br>• *Durability*. Imperviousness of protection to multiple attacks; from delicate systems that are highly vulnerable, to robust mechanisms that are persistently effective even after sustaining many hits. | • Most lethal threat handled by system's protection features. |
| Stealth | • *Design*. Degree to which system's prominence on the battlefield is reduced by modifications in size, shape, surfaces, composition, and overall appearance.<br>• *Emissions*. Extent of measures taken to reduce system's emissions (acoustic, IR, EM, exhaust, etc.); ranging from simple and passive (e.g., heat shields), to sophisticated and active (e.g., noise cancellation).<br>• *Camouflage*. Materials placed on system's surface to help it blend into the background; ranging from specific paint colors and patterns, to foliage-laced netting, to specially-designed synthetic mats.<br>• *Concealment*. Use of natural environment (terrain, foliage, wind, sunlight, etc.) to deliberately avoid detection through careful positioning and movement.<br>• *Deception*. Use of special devices (e.g., decoys) and tactics (e.g., diversions) to confuse enemy or redirect his attention. | • Size of system.<br>• Signature of system, as compared to its context and background.<br>• Conspicuousness of system's typical behavior during combat (e.g., firing signature and frequency). |
| Self-sufficiency | • *Reliability*. Time between failures that significantly degrade functionality.<br>• *Maintenance*. Frequency and duration of necessary service and repairs.<br>• *Endurance*. Typical maximum duration of continuous combat operations. | • Rate at which system's essential supplies are consumed. |

[a] - Definitions of operational, tactical and battlefield mobility are adapted from Simpkin (1979).

## Customization

The rating scale specifications incorporate a variety of assumptions about the importance of various system properties and capabilities, and in some cases refer to examples of specific system types or designs.[42] The following discussion provides the reasoning behind the scale used for each system characteristic, addressing its underlying assumptions and explaining any unusual features.

*Transportability*. The most important determinant of transportability is weight because, in general, heavier systems require more resources, effort, cost and time to transport than lighter systems. Thus, weight decreases as the level of the rating scale increases—the lighter a system is, the easier it is to transport. To make the scale more meaningful, a specific type or class of transport platform is associated with each rating level. The weight range at each level indicates the heaviest vehicle that the platform can carry, with the upper limit roughly equal to the platform's payload capacity.[43] Consider, for example, rating level 5: the C-130 aircraft can carry a vehicle that weighs up to 22 tons (provided that it fits in the cargo bay), while a large helicopter (the level 6 platform) can only carry up to 15 tons, so the C-130 is the smallest platform that a 16–22-ton system can be transported on. Self-deployability is also included as a proxy in this scale to account for differences in the nature of ground vehicles and aircraft; ground vehicles can only deploy themselves by land (subject to restrictions and delays imposed by terrain features, bodies of water, and impassible roads or bridges), while aircraft can fly themselves into a theater (provided that they have air superiority, aerial refueling, and a secure airbase). One feature of this scale also deserves special attention: fast roll-on/roll-off (RORO) sea lift (level 3) is rated higher than C-5/C-17 (level 2) because it provides greater speed, and more

--------

[42] Most of these military systems are described in detail by the Federation of American Scientists web site: http://www.fas.org/man/index.html, last accessed May 22, 2000.

[43] At the low end of the scale the upper limit of the system weight range is somewhat less than the payload capacity because the size and shape of the heaviest systems usually constrain which platforms they can be transported on, rather than just weight.

landing and loading flexibility, although, due to limited deck strength, it may not be able to carry systems that are quite as heavy.

*Mobility*. Range and speed are used to define this scale because they address two key aspects of mobility; maximum on-road range is important in an operational context, while off-road speed is crucial in tactical situations. There are, of course, other aspects of system performance, such as amphibious capabilities, that also affect overall mobility, but improvements in these properties are often correlated with higher range and speed. (Any discrepancies can be accounted for with slightly higher or lower ratings.) The scale level definitions, which change both speed and range in parallel, reflect differences in mobility across a wide range of systems—dismounted infantry at the lowest level, helicopters and other aircraft at the highest levels, and ground vehicles of various types in between.

*Firepower*. The levels of the firepower rating scale are associated with different types or classes of weapons, and are arranged in order of increasing capability. A system is rated at the level that corresponds to its most lethal on-board weapon. The scale encompasses a broad mix of weapons that use different types of energy and attack mechanisms to damage other systems, so traditional measures of lethality, like energy (in MJ) or penetration ability (in mm of RHA), are not mentioned because they only permit similar types of weapons to be compared. As a result, the scale level definitions refer to very different types of weapons; level 3, for example, is associated with small unitary RPG/ATGM (rocket-propelled grenade/anti-tank guided missile), and is wedged between two kinetic energy weapons, 14-30 mm AP (armor piercing) rounds at level 2, and 30-50 mm FS KEP (fin-stabilized kinetic energy penetrator) at level 4.

*Protection*. The scale used for protection is exactly the same as the one used for firepower. These two characteristics are like opposite sides of the same coin; firepower gauges a system's ability to kill other systems, while protection measures its ability to prevent itself from being killed by other systems. In this

case, a system is assigned the rating level that corresponds to the most lethal weapon its defenses can address. (Of course, there may be gaps or other deficiencies in coverage, but the overall rating takes such factors into account.)

**Table 4.5**

**Rating Scale Definitions for System Characteristics**

| | **Transportability** | **Mobility** | **Firepower** | **Protection** | **Stealth** | **Self-sufficiency** |
|---|---|---|---|---|---|---|
| **Proxies**<br><br>**Scale Level** | System weight,<br>Smallest platform,<br>Self-deployability | Maximum range,<br>Typical speed | Most lethal weapon | Most lethal threat addressed | Size,<br>Signature,<br>Behavior<br>(Example) | Consumption rate<br>(Example) |
| 1 | 80+ tons<br>Slow sea lift<br>By land only | 20 km<br>1 km/hr | Small arms | Small arms | Very large<br>Prominent<br>Maneuver and fire<br>(Tank in combat) | Extremely high<br>(Fighter aircraft) |
| 2 | 60-75 tons<br>C-5/C-17<br>By land only | 100 km<br>10 km/hr | 14-30 mm<br>AP rounds | 14-30 mm<br>AP rounds | / \| \\<br>\|<br>\\ \| / | Very high<br>(Attack helicopter) |
| 3 | 40-55 tons<br>Fast RORO sea lift<br>By land only | 200 km<br>30 km/hr | Small Unitary<br>RPG/ATGM | Small Unitary<br>RPG/ATGM | Large<br>Substantial<br>Fire and move<br>(Mobile artillery) | High<br>(Tank) |
| 4 | 25-35 tons<br>SSTOL<br>By land only | 400 km<br>50 km/hr | 30-50 mm<br>FS KEP | 30-50 mm<br>FS KEP | / \| \\<br>\|<br>\\ \| / | Moderately high<br>(Light tank/IFV) |
| 5 | 16-22 tons<br>C-130<br>By land only | 600 km<br>75 km/hr | Small tandem,<br>Large unitary<br>RPG/ATGM | Small tandem,<br>Large unitary<br>RPG/ATGM | Medium<br>Modest<br>Move/hide/fire<br>(Scout vehicle) | Moderate<br>(Tracked APC/<br>scout vehicle) |
| 6 | 12-15 tons<br>Large helicopter<br>By land only | 800 km<br>100 km/hr | Large tandem<br>ATGM,<br>155mm DPICM | Large tandem<br>ATGM,<br>155mm DPICM | / \| \\<br>\|<br>\\ \| / | Moderately low<br>(Wheeled APC/<br>scout vehicle) |
| 7 | 4-10 tons<br>JTR<br>By air in theater | 1000 km<br>125-150 km/hr | 120-125mm<br>KEP,<br>Top EFP | 120-125mm<br>KEP,<br>Top EFP | Small<br>Low<br>Move and hide<br>(Robotic scout) | Low<br>(Hybrid vehicle,<br>infantry team) |
| 8 | 1-3 tons<br>V-22/helicopter<br>By air from region | 1200-1500 km<br>200-400 km/hr | LOSAT<br>EFOG-M | LOSAT<br>EFOG-M | / \| \\<br>\|<br>\\ \| / | Very low<br>(Robotic vehicle,<br>small elite team) |
| 9 | Under 1 ton<br>Small parafoil<br>By air from US | 2000+ km<br>500+ km/hr | 135-150mm<br>KEP | 135-150mm<br>KEP | Very small<br>Minimal<br>Skulk and hide<br>(SOF soldier) | Extremely low<br>(independent<br>system or team) |

*Stealth.* Three proxies are used to define the rating scale for stealth: size, signature, and behavior. If, all else equal, a system is smaller, less prominent on the battlefield, and its actions are less conspicuous, it is less likely to be detected

and targeted by enemy forces. Thus, a smaller size, a lower signature, and less noticeable behavior will make a system more stealthy. The scale for stealth assumes that these three features tend to vary together across different system types, ranging from very large, highly prominent systems with conspicuous behavior, to very small systems that have only a minimal signature and do little that would reveal their presence. To anchor the scale, an example system is included in each scale level definition. Only every other level is defined explicitly, however, since the proxies are qualitative and their specifications are subjective (e.g., small, medium, and large). The implicit definitions of the remaining levels simply split the difference between their adjacent levels.

*Self-sufficiency*. The rate at which essential supplies and services are consumed is the basis for the self-sufficiency rating scale. Systems that use up their supplies and services more slowly generally need to have their stores replenished less often, so they tend to be more self-sufficient than systems with a higher consumption rate. The scale levels are defined by qualitative descriptions of the consumption rate, ranging from extremely high at level 1 up to extremely low at level 9. An example system is also included at each level to provide an anchor for these subjective ratings. These examples are based primarily on the consumption of fuel and maintenance at the low end of the scale, and on food and water consumption at the high end.

## 4.4 OPERATIONAL CHARACTERISTICS

The following five characteristics represent the essential properties of an operational concept in this analysis:

- Awareness: Extent and quality of information provided by intelligence, surveillance, reconnaissance and target acquisition assets.
- Coordination: Ease with which critical information can be exchanged in a timely and secure manner, and then used to inform and execute decisions.

- Adaptability: Capacity to deviate from predetermined plans or conventional procedures in order to respond effectively to unanticipated circumstances.
- Economy: Prudence and efficacy with which force and firepower are allocated on the battlefield.
- Ability to support: Ability of the force to provide itself with the supplies, services and other support necessary for it to maintain operational effectiveness.

Just like their system counterparts, these operational characteristics are distinct from one another and form a complete set, with each member making important contributions to one or more force attributes. Awareness focuses on the knowledge that a force has of its circumstances, as informed by intelligence, surveillance, reconnaissance and target acquisition activities. Coordination gauges the ability of a force to make and implement sensible decisions, which of course depends on its command, control and communications ($C^3$) capabilities. Adaptability is a measure of the flexibility and resourcefulness of a force, which are a byproduct of its organizational design and culture (Fukuyama and Shulsky, 1997). Economy is an indicator of how carefully the fighting resources available to a force, especially firepower, are allocated and used on the battlefield. Ability to support measures how well a force does at providing itself with the supplies and services it requires, given the resources at its disposal. All of these characteristics contribute in a significant way to one or more force attributes: awareness and coordination may be especially important for lethality, maneuverability, and even deployability; adaptability and economy can improve ability to shock, and might even increase survivability; and ability to support is clearly a major source of sustainability.

## Table 4.6

## Contributing Factors and Rating Scale Proxies for Operational Characteristics

| Characteristic | Contributing Factors | Scale Proxies |
|---|---|---|
| Awareness | • *Completeness*. Extent to which all enemy systems on the battlefield are detected and tracked.<br>• *Accuracy*. Correctness of enemy system tracks and associated classifications, and ability to distinguish them from similar civilian or friendly systems.<br>• *Timeliness*. Degree to which information is collected, processed and disseminated quickly enough for it to be of use for planning and targeting. | • Fraction of enemy systems detected when they are: (1) moving in the open; and (2) covered or hidden and not moving.<br>• Likelihood of classification errors in which civilian or friendly systems are mistaken for enemy systems. |
| Coordination | • *Decision support*. Ability to filter and synthesize information from intelligence, surveillance and reconnaissance assets to provide the necessary inputs for command and targeting systems.<br>• *Command-and-control*. Effectiveness of command-and-control structure in developing and executing implementation plans after decisions are made.<br>• *Communications*. Ability to quickly and reliably transmit implementation instructions to ensure that the overall plan is properly executed. | • Overall quality of the decisions made.<br>• Amount of time typically needed to make and implement a decision. |
| Adaptability | • *Initiative*. Ability to seize opportunities and exploit apparent weaknesses.<br>• *Innovation*. Ability to learn from experience and develop new behaviors. | • Degree of autonomy, as evident in the decentralization of decision-making authority to lower echelons (i.e., "organizational flatness").<br>• Degree of latitude that soldiers have in interpreting their commander's intent, as taught and reinforced by education and culture. |
| Economy | • *Positioning*. Careful location and movement of forces and firepower assets to maximize their overall impact.<br>• *Effectiveness*. Overall performance of system's weapons; the product of reliability and accuracy ($P(kill \mid shot) = P(kill \mid hit) \cdot P(hit \mid shot)$).<br>• *Efficiency*. Wise allocation of forces and firepower, | • Targeting precision, in terms of the average number of shots required to kill a single target.<br>• Extent of discrimination among targets in the allocation of fires, to ensure that scarce, costly |

| | | |
|---|---|---|
| | taking into account their cost and availability, as compared to the relative value, both inherent and situational, of their potential targets. | weapons are assigned to the most appropriate and valuable targets. |
| Ability to Support | • *Supply.* Provision of required materials (fuel, food, water, ammunition, etc.) to all force elements.<br>• *Transport.* Movement of supplies and people to where they need to be, when they need to be there.<br>• *Maintenance.* Performance of repairs and routine maintenance with minimal delays, errors and accidents.<br>• *Services.* Provision of services (personnel, medical, etc.) that are essential to ongoing operations. | • Overall adequacy of support provided to force.<br>• Severity of shortfalls in support.<br>• Typical time interval between support problems. |

The scale proxies and contributing factors used to define and refine the rating scales for the five operational characteristics are shown in Table 4.6. The definitions of these scales are shown in Table 4.7. Again, contributing factors are not explicit in the scales, but they can be used to justify a slight adjustment in the corresponding rating of a concept. The rationales for the scales used to rate each operational characteristic are presented below, along with the key assumptions and unusual features of each scale.

## Table 4.7
## Rating Scale Definitions for Operational Characteristics

<table>
<tr><th></th><th>Awareness</th><th>Coordination</th><th>Adaptability</th><th>Economy</th><th>Ability to Support</th></tr>
<tr><td>Proxies<br><br>Scale Level</td><td>Detection rate<br>[in open, covered],<br>Error likelihood<br>(Example)</td><td>Decision quality,<br>Time needed to make and implement decisions</td><td>Degree of...<br>...autonomy,<br>...latitude</td><td>Targeting precision,<br>Discrimination in weapon allocation<br>(Example)</td><td>Adequacy of support,<br>Severity of shortfalls,<br>Time interval between problems</td></tr>
<tr><td>1</td><td>>5%, 0%<br>Usually wrong<br>(Old Maps)</td><td>Atrocious<br>6-12 hours</td><td>Extreme micro-management<br>Strict orders</td><td>500+ shots/kill<br>Indiscriminate<br>(Ordinary artillery)</td><td>Inadequate<br>Severe<br>Minutes</td></tr>
<tr><td>2</td><td>5%, >1%<br>1-in-2<br>(New Maps)</td><td>Very bad<br>3-6 hours</td><td>/ | \<br>|<br>\ | /</td><td>/ | \<br>|<br>\ | /</td><td>/ | \<br>|<br>\ | /</td></tr>
<tr><td>3</td><td>10%, 1%<br>1-in-3<br>(Satellite pictures)</td><td>Bad<br>1-2 hours</td><td>Direct supervision<br>Rigid rules</td><td>100 shots/kill<br>Fairly focused<br>(Advanced artillery)</td><td>Meager<br>Major<br>Hours</td></tr>
<tr><td>4</td><td>25%, 5%<br>1-in-5<br>(Air reconnaissance)</td><td>Moderate-to-bad<br>30-45 minutes</td><td>/ | \<br>|<br>\ | /</td><td>/ | \<br>|<br>\ | /</td><td>/ | \<br>|<br>\ | /</td></tr>
<tr><td>5</td><td>50%, 10%<br>1-in-10<br>(Orbiting UAVs)</td><td>Moderate<br>10-20 minutes</td><td>Hierarchy of teams<br>Specific guidance</td><td>20 shots/kill<br>Very selective<br>(SADARM)</td><td>Sufficient<br>Moderate<br>Days</td></tr>
</table>

| | | | | | |
|---|---|---|---|---|---|
| 6 | 75%, 25%<br>1-in-30<br>(JSTARS) | Moderate-to-good<br>About 5 minutes | /\|\\<br>\|<br>\\\|/ | /\|\\<br>\|<br>\\\|/ | /\|\\<br>\|<br>\\\|/ |
| 7 | 90%, 50%<br>1-in-100<br>(JSTARS P3I) | Good<br>About 1 minute | Independent teams<br>General objectives | 5 shots/kill<br>Judicious<br>(BAT) | Ample<br>Minor<br>Weeks |
| 8 | 95%, 75%<br>1-in-300<br>(UAV-UGS network) | Very good<br>30 seconds or less | /\|\\<br>\|<br>\\\|/ | 3 shots/kill<br>Near perfect<br>(KEP, EFOG-M) | /\|\\<br>\|<br>\\\|/ |
| 9 | 99%, 90%<br>1-in-1000+<br>(Advanced ISR net.) | Excellent<br>10 seconds or less | Individual agents<br>Broad goals | 1 shot/kill<br>Optimal<br>(Advanced LOSAT) | Robust<br>Minimal<br>Months |

*Awareness*. The rating scale for awareness is defined in terms of the rate at which enemy forces can be detected, and the likelihood that civilians or friendly systems with be mistakenly identified as enemy forces. Two different detection rates are considered, one for enemy systems in the open, and the other for those that are hiding under cover, with the former always somewhat higher than the latter. These proxies represent two different aspects of awareness: detection rates indicate how often we find what we are looking for, while error likelihood indicates how often what we have found is not what we are looking for, but we think it is. Detecting more enemy forces improves situational awareness because it allows U.S. and allied forces to plan their actions more effectively, react faster to avoid pitfalls and exploit opportunities, and reduce the likelihood that they will be surprised. Making fewer errors in discriminating civilians and friendly forces from the enemy will reduce the frequency and severity of fratricide and collateral damage incidents. This rating scale assumes that both of these quantitative measures improve in parallel as overall awareness becomes more advanced; at the low end of the scale detection rates are very low and error likelihood is very high, while at the high end of the scale detection rates are very high and error likelihood is very low. An example intelligence, surveillance and reconnaissance (ISR) system is also associated with each level of the scale to provide an anchor point for the corresponding level of awareness.

*Coordination*. The rating scale for coordination is defined using two measures of decision-making effectiveness: the overall quality of command

decisions, and the time needed to make and implement such decisions. As coordination increases, decision quality generally improves, and the time required by commanders to make decisions, communicate them to their subordinates, and have them implemented, is reduced. In the scale level definitions, decision quality is expressed by subjective assessments, ranging from atrocious to excellent, while the time needed to implement decisions is given in intervals that range from 6-12 hours to 10 seconds or less.[44]

*Adaptability.* The rating scale for adaptability relies on qualitative assessments of the degree of autonomy and latitude that are present in the organization and culture of a force when it is using a given operational concept. As the autonomy and latitude of individual soldiers increases, the adaptability of the force as a whole will generally increase as well, thereby making it more flexible and responsive, and, ultimately, more effective. To make this point, Fukuyama and Shulsky (1997) discuss how the German Army's emphasis on decentralization and independent maneuver contributed to its early successes in World War Two. Referring to German land warfare field manuals of the time, Van Creveld (1982; pp. 32-33) explains that the Germans tended to avoid formalized rules because they viewed war as more of an art than a science. The autonomy assessments used to define the scale levels indicate the amount of organizational "flattening," or decentralization, in the force, and the extent of the control exerted by its commanders, ranging from extreme micro-management to uncontrolled individual agents. The latitude assessments indicate the stringency of the rules that govern the decision making behavior of individuals in the force. The scale assumes that both autonomy and latitude increase together as a force becomes more adaptable.

*Economy.* The economy of an operational concept is rated according to the precision and discrimination with which it allocates the assets of the force

--------

[44] The impact of command-and-control delays on weapon effectiveness, for example, is

(primarily weapons, but also troops and equipment). The more precisely those assets are allocated (weapons targeted, troops positioned, etc.), and the more discriminating that allocation is, in terms of ensuring that its benefits warrant its costs, the more economic the force. To make the scale level definitions more concrete, both proxies are applied to the allocation of weapons; targeting precision is measured quantitatively, in shots per kill, while discrimination is defined subjectively, using qualitative assessments of weapon allocation efficiency, ranging from indiscriminate to optimal. Only every other level is defined explicitly, except for the highest three levels, so the definitions of the remaining levels (2, 4 and 6) are implicit. A type of weapons system is also provided as an example of the degree of economy at each defined level. While this scale is used to rate operational concepts, these system examples provide a specific, tangible point of reference.

*Ability to Support.* Ratings of ability to support are defined with qualitative statements regarding three aspects of support: its overall adequacy, the severity of any shortfalls in supplies or services, and the typical time interval between problems. The more adequate the support provided, the milder the shortages, and the more infrequent problems are, the greater an operational concept's ability to support the force will be. The joint ratings on these three criteria range from inadequate support, with severe shortfalls and problems every few minutes, all the way up to robust support, with minimal shortages and problems only every few months. Every other scale level is defined in this manner; the definitions of the remaining levels are implicit.

## 4.5 SYSTEM ROLES

The relative importance of a system's characteristics are determined by the role it plays in a force. For example, protection is much more important in a role that involves direct contact with armored enemy forces than in a long-range fire

---

examined by Matsumura et al. (1997).

support role. Nine roles are used to capture such differences in this analysis. A definition and an example system are provided below for each of these roles:

1. Direct Fire Attack: Move to contact enemy forces, and then fight them directly using line-of-sight weapons at relatively short distances (< 5 km). Example: main battle tank.

2. Direct Fire Support: Avoid direct contact with enemy forces while providing infantry and line-of-sight fires from short to moderate range (2 – 5 km) to support more capable forces (both direct-fire and long-range indirect-fire). Example: infantry fighting vehicle with ATGMs.

3. Indirect Fire Close: Stay out of direct contact with enemy forces while providing short to moderate range non-line-of-sight fires (5 – 20 km). Example: short-range rocket, mortar and cannon artillery.

4. Indirect Fire Far: Provide moderate to long range non-line-of-sight fires from areas beyond the direct influence of enemy forces (20 – 300 km). Example: multiple rocket launcher with long-range missiles.

5. Close Air Support: Attack enemy ground forces from the air using a mix of line-of-sight direct fires and short to moderate range indirect fires (5 – 20 km), with the intent of hitting enemy forces just before their direct-fire systems are in a position to attack friendly ground forces. Example: attack helicopter.

6. Deep Air Interdiction: Attack enemy forces in areas under their control—combat elements near the front and reserve or support elements in the rear—from very long ranges (>300 km). Example: cruise missile.

7. Reconnaissance Scout: Operate in varied locations to gather and interpret battlefield information from both human observations and multiple sensors, then disseminate it to the other elements of the force. (Systems in this role can be manned or unmanned, and air- or ground-based.) Example: scout vehicle.

8. Reconnaissance Strike: Roam on or over large portions of the battlefield to determine the location, strength and disposition of enemy forces, disseminate

this information to other force elements, and then, if it is both feasible and appropriate, attack enemy systems with a mix of line-of-sight direct fires and moderate range indirect fires. Example: reconnaissance-attack helicopter.

9. Special Operations: Insert into enemy-controlled areas undetected to perform various activities intended to distract and degrade enemy forces, or facilitate attacks against them. Example: small sabotage and assault team.

These roles represent the groupings of tasks and activities that systems tend to engage in on the battlefield. A single role from this set is assigned to each component system based on its design and primary function. For example, a main battle tank would be assigned to the "direct fire attack" role because it best describes what this system is designed for. It is conceivable, of course, that the a system could play a different role in certain missions, or even when it is a part of a different type of force. To keep this demonstration of the HIMAX approach from becoming unnecessarily complex, however, it is assumed that each system always plays the same role in every mission, and for any option.

## 4.6 CONCLUDING REMARKS

This chapter described how the HIMAX process, and its decision model, in particular, were customized to for the evaluation of future military force options. This involved selecting and defining the missions, characteristics, attributes and roles that are used in this model. Chapter 5 presents the structure of the analysis conducted using this customized version of the HIMAX process, and describes the specifics of the options that are evaluated in this analysis. The rest of the initial preparation phase is then described in Chapter 6.

## 5. STRUCTURE OF THE ANALYSIS

This chapter describes the structure of an analysis that demonstrates the HIMAX process by applying it to a real, complex policy problem. The chapter begins by describing the two time frames that the analysis is organized around, and introducing the five types of force options that are considered in each time frame. Next, the composition of the options, and the characteristics of the systems and operational concepts that comprise them, are presented for each time frame. This chapter ends by discussing a few key option comparisons, having set the stage for the chapters that follow, which describe the results.

### 5.1 TIME FRAMES AND OPTIONS TYPES

The analysis consists of two separate evaluations, which compare a range of different force options in two time frames:

*Near Term (2005 – 2010).* The options considered for the near term are "evolutionary" in nature. They do not include any entirely new systems or operational technologies. All of the component systems and operational concepts already exist, or involve only incremental improvements in existing systems and concepts, such as the addition of minor design modifications, or the introduction of mature or recently-developed technologies.

*Far Term (2015 – 2025).* The options considered for the far term are more "revolutionary" than the near-term options. They include improved versions of existing systems, and some systems that are entirely new. These new systems incorporate various technologies that are extremely promising, but, as yet, undeveloped and unproven. The impact of advanced technology is also reflected in the characteristics of the far-term operational concepts.

The purpose of this division in the analysis is two-fold. It avoids the temptation to mix risky, unproven technologies and systems, which could take

many years to develop, with incremental force improvements that can be attained within just a few years. This approach still allows more aggressive revolutionary options to be considered, but it places them in an appropriately distant time frame. Keeping the evaluations separate ensures that the options compared in each time frame share a common technological basis.

The same five types of force options are considered for each time frame: (1) heavy armored, (2) medium-weight, (3) light infantry, (4) "air only" standoff (aircraft and long-range missiles), and (5) "air + SOF" standoff (aircraft and long-range missiles, plus teams of special operations forces). In each time frame, these options have somewhat different names, and consist of different mixes of systems and operational concepts. In some cases, these differences are minor, involving slightly different numbers of the same systems, or improved versions of them, and the same operational concepts in similar proportions; in others, the two options are composed of different systems, and use different concept mixes.

Force options are composed of systems from two different sets—one for the near term and the other set for the far term—and a combination of operational concepts from a single common set. The near-term and far-term component systems are listed and described in Tables 5.1 and 5.2, respectively.[45] The five operational concepts described in Table 5.3 are used in both time frames, but have somewhat different characteristics in each to reflect changes in technology, tactics and other factors over time. The following two subsections describe the composition of the five options considered in each time frame[46], and discuss the characteristics of their components.[47]

--------

[45] These force options are roughly equivalent to a typical U.S. Army brigade, in terms of their organizational scope, the area they can cover, and how they would be used. Many of the component systems in these options are described by the Federation of American Scientists web site: http://www.fas.org/man/index.html, last accessed May 22, 2000.

[46] The composition of these force options was developed in consultation with RAND's two principal force-on-force simulation gamers, who have extensive experience composing forces like these to use in analyses for the Army, the Office of the Secretary of Defense, and other

**Table 5.1**

**Component Systems of Near-Term Force Options**

| Name of System | Description |
|---|---|
| M1A2 | Most recent version of Abrams main battle tank |
| M2A3/M3A3 | Most recent version of Bradley fighting vehicle (M2: infantry; M3: cavalry) |
| M2A3-FGM | Infantry version of Bradley fighting vehicle, enhanced fiber-optic guided missiles (EFOG-M) |
| M109A6 | Paladin self-propelled 155mm howitzer |
| MLRS | M270 Multiple Launch Rocket System (MLRS), standard M26 rockets with AT2 warheads |
| LAV-DFV | Direct fire version of light armored vehicle (LAV), 105mm soft-recoil gun |
| LAV-IFV | Infantry fighting vehicle version of LAV, 35mm cannon and TOW anti-tank guided missile (ATGM) |
| LAV-APC | Armored personnel carrier (APC) version of LAV, 50-caliber machine gun |
| LAV-MOR | Self-propelled 120mm mortar version of LAV |
| LAV-HOW | APC version of LAV with towed 155mm howitzer |
| LAV-FGM | LAV mounted with EFOG-M |
| LAV-REC | Reconnaissance/scout version of LAV with telescoping sensor mast |
| HIMARS | High mobility multiple rocket system, Army tactical missile system (ATACMS) with brilliant anti-tank (BAT) munitions (1 launcher) |
| HMMWV-TOW | High mobility multi-wheeled vehicle (HMMWV), TOW ATGM |
| Javelin team | Dismounted infantry teams, Javelin hand-held ATGM |
| Mortar team | Dismounted infantry teams, portable mortar tubes |
| HMMWV-HOW | HMMWV with a towed 155mm howitzer |
| HMMWV-FGM | HMMWV with EFOG-M |
| AH-64D | Apache Longbow attack helicopter with Hellfire ATGM |
| A-10 | Thunderbolt armored ground-attack aircraft |
| TAC-AIR | F-16E fighter-bomber with precision guided munitions (PGM) |
| NTACMS | Long-range Navy tactical missile system with brilliant anti-tank (BAT) munitions (2 launchers) |
| SOF-RST | Team of special operations forces (SOF), trained for reconnaissance, surveillance and target acquisition (RST) |

---

defense agencies. They were provided with a list of systems for each option and then asked to provide an estimate of how many of them would be included in a brigade-sized force. They also estimated how often the forces would use each of the operational concepts. They compared their initial estimates and then provided a set of consensus responses, which form the basis for the numbers used in the analysis.

[47] The characteristic rating distributions were generated using a more subjective approach. The author estimated both the median values and the ±1 probabilities using a variety of sources, including his own knowledge of the systems from previous work. These estimates were then reviewed by a member of the dissertation committee to ensure that they were reasonable and consistent. These inputs were finalized at the outset, and none of them were altered during the course of the analysis. Nonetheless, they should be viewed as illustrative, rather than definitive.

**Table 5.2**

**Component Systems of Far-Term Force Options**

| Name of System | Description |
|---|---|
| M1A3 | Improved version of Abrams main battle tank, 140mm main gun |
| M2A4 | Improved version of Bradley (infantry) fighting vehicle (IFV), new 50mm gun and follow-on-to-TOW (FOTT) ATGM |
| M2A4-FGM | Improved Bradley with EFOG-M |
| Crusader | Advanced self-propelled 155mm howitzer (and re-supply vehicle) |
| MLRS | M270 MLRS, ATACMS with BAT (2 launchers) |
| FSCS | Future Scout Cavalry System (FSCS) reconnaissance/scout vehicle with telescoping sensor mast and signature reduction |
| FCS-DFV | Direct fire version of Future Combat System (FCS), advanced 105mm gun or line-of-sight anti-tank (LOSAT) hypervelocity missile |
| FCS-IFV | IFV version of FCS, with 50mm gun and FOTT ATGM |
| FCS-APC | APC version of FCS |
| FCS-ART | Artillery version of FCS, 120mm howitzer/mortar with PGM |
| FCS-REC | Reconnaissance/scout version of FCS with telescoping sensor mast |
| ARES | Advanced Robotic Engagement System (ARES); mobile, remote-control missile launcher |
| Adv. MLRS | Wheeled 8-ton version of MLRS, ATACMS with BAT (1 pod) |
| AHMV-FOT | Advanced High Mobility Vehicle (AHMV), FOTT ATGM |
| AHMV-APC | APC version of AHMV |
| RST-V | Small, manned reconnaissance, surveillance and targeting vehicle |
| Adv. Javelin | Dismounted infantry teams with improved Javelin hand-held ATGM |
| Adv. Mortar | Dismounted infantry teams with portable 120-mm mortars |
| Small AFSS | Small version of Advanced Fire Support System (AFSS); "missiles in a box" |
| Large AFSS | Large version of AFSS |
| AH-64D+ | Improved version of Apache Longbow attack helicopter |
| RAH-66 | Comanche reconnaissance-attack helicopter |
| Adv. TAC-AIR | Ground-attack version of Joint Strike Fighter (JSF) with advanced PGM |
| Adv. NTACMS | Improved version of NTACMS with advanced PGM |
| SOF-RST | SOF team for RST; uses a mix of human and robotic elements |
| SOF-AST | SOF team specializing in assault and sabotage in enemy territory |

## 5.2 "EVOLUTIONARY" OPTIONS FOR THE NEAR TERM (2005 – 2010)

This section describes the five near-term force options, and discusses the characteristics of their system and operational components. Two tables provide detailed information regarding the composition of these near-term options. Table 5.4 indicates the quantity of each system in every option, along with the

role assigned to it. Table 5.5 shows the mix of operational concepts used by each option. Two additional tables show the median ratings of each near-term force component on their respective rating scales[48]; the system characteristics of each system are shown in Table 5.6, and the operational characteristics of each concept are shown in Table 5.7. Both of these tables also include the probability distribution assigned to each characteristic rating, expressed as a triplet of numbers that sum to one[49], which represents performance variations due to technological and environmental uncertainty. The following descriptions refer implicitly to the information presented in Tables 5.4, 5.5, 5.6 and 5.7 as they discuss the composition of each near-term option, and the characteristics of its components.

**Table 5.3**

**Operational Concepts Used in Both Near- and Far-Term Force Options**

| Name | Description |
|---|---|
| Standoff (no ground info) | Attack targets in enemy territory by air or from long range, using only overhead imagery or other external intelligence for targeting |
| Standoff (w/ ground info) | Use sensors or observers on the ground to locate targets in enemy territory, and direct precision fires or air attacks onto them |
| Maneuver Warfare | Use mobile ground and air forces with direct fires (i.e., combined arms) to attack enemy, exploit weaknesses, and maneuver to gain advantage |
| Ambush/ Envelopment | Insert forces and attack quickly to surprise, disrupt, confuse and stun enemy forces, thereby creating an opportunity to win early at lower cost |
| Peace Keeping/ Enforcement | Create order under a peace agreement by entering rapidly, establishing a visible presence, and responding quickly and forcefully to violations |

--------

48 The system and operational rating scales are shown in Tables 4.5 and 4.7, respectively.

49 These numbers represent, respectively, the probabilities that the rating is one notch lower than, exactly at, and one notch higher than the median rating. For example, if the median rating for mobility is 5, and its distribution triplet is (0.2, 0.7, 0.1), then there would be a 20% chance that mobility is at level 4, a 70% chance that it is at 5, and a 10% chance that it is at 6.

## Heavy

This force is composed primarily of Abrams main battle tanks (M1A2) and Bradley fighting vehicles (M2A3/M3A3). These two vehicles both play a direct fire role, with the M1A2 in attack, and the M2A3/M3A3 in support. The M1A2 has more firepower and protection than the M2A3/M3A3, but rates slightly lower on stealth, transportability and self-sufficiency because it is larger, heavier and less fuel-efficient. The remaining ground vehicle systems—the Bradley with an Enhanced Fiber-Optic Guided Missile (EFOG-M) system, the Paladin M109A6 self-propelled howitzer, and the M270 Multiple-Launch Rocket System (MLRS)—all play an indirect fire close role in the force. The EFOG-M version of the Bradley (M2A3-FGM) has more firepower than the basic infantry or cavalry version, but also has less protection, since it does not have reactive armor and other survivability-enhancing features that are standard on the M2A3/M3A3. Aside from differences in firepower, the characteristics of the MLRS and the Paladin are similar to those of the M2A3-FGM, with the Paladin somewhat weaker on mobility and self-sufficiency, since it is a bit slower and requires more support. A small contingent of a dozen dismounted infantry teams with the Javelin ATGM system is also included in this force to provide security support. Because these teams are dismounted, their characteristics are highly unbalanced; they are extremely weak on mobility and protection, since they have no armored vehicles, but they are very strong on transportability, stealth and self-sufficiency, since they are very light, very small, and not very dependent on support.

The heavy force also includes a substantial air element, consisting of three companies of Apache Longbow attack helicopters (AH-64D), and a fully-deployed air expeditionary force (AEF) that includes about equal numbers of ground-attack aircraft (A-10), and tactical fighter-bombers (TAC-AIR) with

precision guided munitions (PGM)[50]. The AH-64D and the A-10 both play a close air support role in this force, while TAC-AIR plays a deep air interdiction role. All of these aircraft are fast and have some ability to self-deploy, so they rate highly on both mobility and transportability. They are only moderately strong on firepower and stealth, and weak on protection (less so for the A-10), since they rely on speed, agility and distance to be elusive. They are also weak on self-sufficiency, since they consume fuel rapidly and require extensive support. The heavy force also has at its disposal a total of 18 Navy tactical missile systems (NTACMS)—which are similar to the Army's ATACMS, with two pods per system—that play a deep air interdiction role. In addition to providing a high level of firepower, these missile launchers are also strong on transportability, self-sufficiency and stealth, because they are on U.S. Navy ships, which deploy and support themselves, and are fairly hard for enemy ground forces to find. The NTACMS is also moderately weak on mobility, which is determined by the speed and range of its host ship, and is very weak on protection, since it has no defenses of its own.[51]

As Table 5.5 shows, the heavy force relies mostly on maneuver warfare, but also uses three other operational concepts—standoff (with ground information), ambush/envelopment, and peace keeping/enforcement—about equally. The characteristics of the maneuver warfare concept are fairly balanced, with moderate ratings on adaptability and ability to support, and somewhat stronger ratings on economy, awareness and, to a lesser extent, coordination. These balanced characteristics stem from this concept's reliance on combined arms, robust organization, careful preparation, and flexible implementation (U.S. Army, 1993).

--------

[50] According to Cook (1998), a full AEF would include a total of 26 A-10s, and 24 F-16s with PGM (consisting of 12 A-10s and 10 F-16Es forward-deployed, and 14 of each on-call).

[51] The host ship may, of course, have defensive systems that provide the NTACMS with added protection, but his was not assumed to be the case in this analysis.

**Table 5.4**

**Roles and Quantities of Systems in Near-Term Force Options**

| | | Quantity, by Force Option | | | | |
|---|---|---|---|---|---|---|
| **System** | **Role*** | Heavy | Medium | Light | Air Only | Air + SOF |
| M1A2 | 1 | 56 | 0 | 0 | 0 | 0 |
| M2A3/M3A3 | 2 | 44 | 0 | 0 | 0 | 0 |
| M2A3-FGM | 3 | 8 | 0 | 0 | 0 | 0 |
| M109A6 | 3 | 16 | 0 | 0 | 0 | 0 |
| MLRS | 3 | 12 | 0 | 0 | 0 | 0 |
| LAV-DFV | 1 | 0 | 28 | 0 | 0 | 0 |
| LAV-IFV | 2 | 0 | 30 | 0 | 0 | 0 |
| LAV-APC | 2 | 0 | 28 | 0 | 0 | 0 |
| LAV-MOR | 3 | 0 | 8 | 0 | 0 | 0 |
| LAV-HOW | 3 | 0 | 12 | 0 | 0 | 0 |
| LAV-FGM | 3 | 0 | 16 | 0 | 0 | 0 |
| LAV-REC | 7 | 0 | 12 | 0 | 0 | 0 |
| HIMARS | 4 | 0 | 6 | 0 | 0 | 0 |
| HMMWV-TOW | 2 | 0 | 0 | 24 | 0 | 0 |
| Javelin team | 2 | 12 | 12 | 24 | 0 | 0 |
| Mortar team | 3 | 0 | 0 | 9 | 0 | 0 |
| HMMWV-HOW | 3 | 0 | 0 | 8 | 0 | 0 |
| HMMWV-FGM | 3 | 0 | 0 | 12 | 0 | 0 |
| AH-64D | 5 | 24 | 16 | 8 | 0 | 16 |
| A-10 | 5 | 26 | 26 | 12 | 0 | 26 |
| TAC-AIR | 6 | 24 | 24 | 10 | 72 | 24 |
| NTACMS | 6 | 18 | 12 | 6 | 18 | 18 |
| SOF-RST | 9 | 0 | 0 | 0 | 0 | 30 |

* - Key for system roles: (1) direct fire attack, (2) direct fire support, (3) indirect fire close, (4) indirect fire far, (5) close air support, (6) deep air interdiction, (7) reconnaissance scout, (8) reconnaissance attack, (9) special operations.

## Medium[52]

This force option is built around the eight-wheeled Light Armored Vehicle (LAV).[53] Roughly equal numbers of DFV, IFV and APC versions of the LAV form the core of this force, all playing direct fire roles (DFV in attack, and IFV and APC in support). Close-range indirect fire support is provided by smaller

---

[52] This "medium" option resembles the Light Recon-Strike Group described by Macgregor (1997), and is similar to the medium-weight force advocated by Gordon and Wilson (1998, 1999).

numbers of other LAV variants carrying an EFOG-M (FGM), a towed 155mm howitzer (HOW), or a 120mm mortar (MOR). These vehicles each provide a different degree of firepower, depending on their function and armament, and they all have a moderate level of transportability, mobility and self-sufficiency, because they are relatively light, fast and fuel-efficient vehicles. They are, however, a bit weak on protection and stealth since they lack advanced defensive features, but still have to behave like fully-armored systems. Longer range indirect fire is provided by several HIMARS—trucks with one ATACMS pod—which have considerable firepower, and are moderately transportable, mobile and self-sufficient, due to their low weight, range and quickness, and overall efficiency. They are not well-protected or particularly stealthy, however, since they have no armor and are quite conspicuous when they fire. Several LAV reconnaissance variants (REC), which have little firepower, but are fairly stealthy, are also included in the force, along with a dozen dismounted Javelin teams. The air and missile element of this option is similar to that of the heavy force, except that it has one third fewer Apaches and NTACMS.

The medium option employs standoff (with ground information) and ambush/envelopment about equally, and uses them twice as often as maneuver warfare and peace keeping/enforcement, resulting in usage proportions of 1/3, 1/3, 1/6 and 1/6, respectively. The standoff (with ground information) concept is balanced, like maneuver warfare, but is slightly weaker across the board, with its weakest rating in adaptability. These deficiencies are due mainly to poorer intelligence, longer communication delays, more rigid rules of engagement, less efficient targeting, and weaker support infrastructures. Ambush/envelopment is also a well-balanced concept, but is superior to maneuver warfare on most characteristics. It has particularly high ratings for coordination, adaptability and

---

[53] The LAV vehicles in the near-term medium force are based on the new LAV-III, not the older LAV-25 version.

ability to support, since it relies on efficient, well-trained, independent teams with substantial flexibility to execute short, focused, well-planned missions.

**Table 5.5**

**Mix of Operational Concepts Used by Near-Term Force Options**

| | Proportion of Use, by Force Option | | | | |
|---|---|---|---|---|---|
| **Operational Concept** | Heavy | Medium | Light | Air Only | Air + SOF |
| Standoff (no ground info) | 0 | 0 | 0 | 1 | 0 |
| Standoff (w/ ground info) | 0.143 | 0.333 | 0.333 | 0 | 1 |
| Maneuver Warfare | 0.571 | 0.167 | 0 | 0 | 0 |
| Ambush/ Envelopment | 0.143 | 0.333 | 0 | 0 | 0 |
| Peace Keeping/ Enforcement | 0.143 | 0.167 | 0.667 | 0 | 0 |

## Light

This near-term light force option includes three types of high mobility multi-wheeled vehicle (HMMWV), each equipped with a different weapon—an ATGM version with TOW, an FGM version with EFOG-M, and an HOW version with a towed 155mm howitzer—to give it a moderate level of firepower. These HMMWV variants are all very light, so they have a high level of transportability. They are also fairly quick, small and efficient, so they have moderate levels of mobility, stealth and self-sufficiency as well. But, because of their minimal armor they have very little protection. This force also includes twice as many Javelin teams as the heavy or medium option, and several mortar teams as well. Both of these dismounted systems have similar characteristics; they have a moderate level of firepower, are highly transportable and quite stealthy and self-sufficient, but have very little mobility or protection. The light force's air and missile element includes only the forward-deployed part of an AEF (Cook, 1998), and one third as many Apaches and NTACMS as the heavy option, since it must respond rapidly with the air and sea forces that are already in the conflict region.

## Table 5.6

## Characteristic Ratings of Near-Term Systems

| System | System Characteristics | | | | | |
|---|---|---|---|---|---|---|
| | Transport-ability | Mobility | Firepower | Protection | Stealth | Self-sufficiency |
| M1A2 | 2 (0.0, 1.0, 0.0) | 4 (0.2, 0.5, 0.3) | 7 (0.0, 1.0, 0.0) | 6 (0.1, 0.6, 0.3) | 1 (0.0, 0.8, 0.2) | 3 (0.2, 0.8, 0.0) |
| M2A3/ M3A3 | 4 (0.0, 1.0, 0.0) | 4 (0.0, 0.7, 0.3) | 5 (0.0, 1.0, 0.0) | 4 (0.1, 0.6, 0.3) | 2 (0.0, 0.8, 0.2) | 4 (0.4, 0.6, 0.0) |
| M2A3-FGM | 4 (0.0, 1.0, 0.0) | 4 (0.0, 0.7, 0.3) | 8 (0.0, 1.0, 0.0) | 2 (0.0, 0.6, 0.4) | 2 (0.0, 0.6, 0.4) | 4 (0.2, 0.8, 0.0) |
| M109A6 | 4 (0.0, 1.0, 0.0) | 3 (0.0, 0.6, 0.4) | 6 (0.0, 0.8, 0.2) | 2 (0.0, 0.8, 0.2) | 3 (0.2, 0.8, 0.0) | 3 (0.2, 0.6, 0.2) |
| MLRS | 4 (0.0, 0.9, 0.1) | 4 (0.0, 0.7, 0.3) | 6 (0.0, 0.7, 0.3) | 2 (0.0, 0.6, 0.4) | 3 (0.1, 0.9, 0.0) | 4 (0.2, 0.8, 0.0) |
| LAV-DFV | 5 (0.2, 0.8, 0.0) | 5 (0.3, 0.6, 0.1) | 6 (0.0, 1.0, 0.0) | 3 (0.3, 0.7, 0.0) | 2 (0.0, 0.6, 0.4) | 5 (0.3, 0.7, 0.0) |
| LAV-IFV | 5 (0.0, 1.0, 0.0) | 5 (0.3, 0.6, 0.1) | 5 (0.0, 1.0, 0.0) | 3 (0.3, 0.7, 0.0) | 3 (0.4, 0.6, 0.0) | 5 (0.0, 1.0, 0.0) |
| LAV-APC | 5 (0.0, 1.0, 0.0) | 5 (0.3, 0.6, 0.1) | 2 (0.0, 1.0, 0.0) | 3 (0.3, 0.7, 0.0) | 4 (0.0, 0.8, 0.2) | 5 (0.0, 1.0, 0.0) |
| LAV-MOR | 5 (0.0, 1.0, 0.0) | 5 (0.3, 0.6, 0.1) | 6 (0.0, 0.9, 0.1) | 2 (0.2, 0.7, 0.1) | 3 (0.0, 0.8, 0.2) | 5 (0.2, 0.8, 0.0) |
| LAV-HOW | 5 (0.2, 0.8, 0.0) | 4 (0.2, 0.6, 0.2) | 6 (0.0, 0.9, 0.1) | 2 (0.2, 0.7, 0.1) | 3 (0.0, 0.8, 0.2) | 5 (0.2, 0.8, 0.0) |
| LAV-FGM | 5 (0.0, 1.0, 0.0) | 5 (0.3, 0.6, 0.1) | 8 (0.0, 1.0, 0.0) | 2 (0.2, 0.7, 0.1) | 3 (0.0, 0.8, 0.2) | 5 (0.2, 0.8, 0.0) |
| LAV-REC | 5 (0.0, 1.0, 0.0) | 5 (0.3, 0.6, 0.1) | 2 (0.2, 0.8, 0.0) | 2 (0.2, 0.7, 0.1) | 5 (0.3, 0.7, 0.0) | 5 (0.0, 0.6, 0.4) |
| HIMARS | 6 (0.1, 0.9, 0.0) | 5 (0.3, 0.6, 0.1) | 7 (0.0, 1.0, 0.0) | 1 (0.0, 1.0, 0.0) | 3 (0.0, 0.8, 0.2) | 5 (0.1, 0.8, 0.1) |
| HMMWV-TOW | 7 (0.0, 1.0, 0.0) | 5 (0.4, 0.4, 0.2) | 5 (0.0, 1.0, 0.0) | 2 (0.4, 0.6, 0.0) | 4 (0.0, 0.7, 0.3) | 6 (0.1, 0.9, 0.0) |
| Javelin team | 9 (0.0, 1.0, 0.0) | 1 (0.0, 1.0, 0.0) | 5 (0.0, 1.0, 0.0) | 1 (0.0, 1.0, 0.0) | 7 (0.0, 0.6, 0.4) | 7 (0.3, 0.5, 0.2) |
| Mortar team | 9 (0.0, 1.0, 0.0) | 1 (0.0, 1.0, 0.0) | 6 (0.0, 0.9, 0.1) | 1 (0.0, 1.0, 0.0) | 7 (0.0, 0.6, 0.4) | 7 (0.0, 0.8, 0.2) |
| HMMWV-HOW | 7 (0.0, 1.0, 0.0) | 4 (0.2, 0.6, 0.2) | 6 (0.0, 0.9, 0.1) | 1 (0.0, 0.8, 0.2) | 4 (0.3, 0.7, 0.0) | 6 (0.2, 0.8, 0.0) |
| HMMWV-FGM | 7 (0.0, 1.0, 0.0) | 5 (0.4, 0.4, 0.2) | 8 (0.0, 1.0, 0.0) | 1 (0.0, 0.8, 0.2) | 4 (0.2, 0.8, 0.0) | 6 (0.2, 0.8, 0.0) |
| AH-64D | 7 (0.3, 0.6, 0.1) | 8 (0.3, 0.7, 0.0) | 6 (0.2, 0.6, 0.2) | 2 (0.0, 0.8, 0.2) | 5 (0.33, 0.34, 0.33) | 1 (0.0, 0.8, 0.2) |
| A-10 | 8 (0.0, 0.6, 0.4) | 9 (0.1, 0.9, 0.0) | 6 (0.0, 0.6, 0.4) | 4 (0.2, 0.8, 0.0) | 6 (0.2, 0.4, 0.4) | 1 (0.0, 0.5, 0.5) |
| TAC-AIR | 9 (0.2, 0.8, 0.0) | 9 (0.0, 1.0, 0.0) | 7 (0.5, 0.4, 0.1) | 2 (0.0, 0.5, 0.5) | 7 (0.0, 0.6, 0.4) | 1 (0.0, 0.7, 0.3) |

| System | System Characteristics | | | | | |
|---|---|---|---|---|---|---|
| | Transport-ability | Mobility | Firepower | Protection | Stealth | Self-sufficiency |
| NTACMS | 8 (0.2, 0.6, 0.2) | 3 (0.0, 0.7, 0.3) | 7 (0.1, 0.8, 0.1) | 1 (0.0, 1.0, 0.0) | 8 (0.33, 0.34, 0.33) | 7 (0.2, 0.6, 0.2) |
| SOF-RST | 8 (0.0, 0.6, 0.4) | 1 (0.0, 0.8, 0.2) | 1 (0.0, 1.0, 0.0) | 1 (0.0, 1.0, 0.0) | 8 (0.0, 0.75, 0.25) | 8 (0.0, 0.6, 0.4) |

NOTE: The median m and probability distribution (P[m-1], P[m], P[m+1]) are shown in each cell. A higher value on the 1-to-9 rating scale indicates a more positive level of the characteristic.

The light force uses peace keeping/enforcement and standoff (with ground information) in a ratio of two to one. The peace keeping/enforcement concept is rated highly on ability to support because it is used mostly in low-intensity situations, where supply lines are fairly secure. This concept is moderately strong on awareness and economy as well, since available intelligence can be used to allocate resources fairly well, but is weaker on adaptability and coordination, due to strict rules of engagement and the command and control difficulties they create. In combat situations, the light force uses the standoff (with ground information) concept, which provides more awareness and coordination, since intelligence-gathering and decision-making are more straightforward, but does not rate as highly for ability to support because supply lines may be tenuous, or even nonexistent.

## Air Only

There are no ground vehicles in this pure standoff force, which is composed entirely of TAC-AIR and NTACMS in a ratio of four to one. AH-64D helicopters and A-10 aircraft are not included in this force, since they are most effective when used in concert with some type of ground force element. The air only option uses just one operational concept: standoff (no ground information). This concept has a moderately high rating for ability to support, and a moderate rating for coordination, since it focuses on the application of air power, which is deployed with effective infrastructures for support, and for command, control and communications (C3). It is, however, slightly weak on awareness and economy, since it lacks reliable intelligence and can have difficulty finding and

hitting high-value targets on the battlefield. The air only force is especially weak on adaptability because it has to use very tight rules of engagement to minimize collateral damage, since aircraft have such difficulty discriminating between military targets and civilians without ground-based confirmation.

**Table 5.7**

**Characteristic Ratings of Near-Term Operational Concepts**

| Operational Concept | Operational Characteristic: Awareness | Coordination | Adaptability | Economy | Ability to Support |
|---|---|---|---|---|---|
| Standoff (no ground info) | 4 (0.1, 0.7, 0.3) | 5 (0.1, 0.8, 0.1) | 2 (0.2, 0.6, 0.2) | 4 (0.3, 0.6, 0.1) | 6 (0.4, 0.4, 0.2) |
| Standoff (w/ ground info) | 6 (0.0, 0.6, 0.4) | 5 (0.3, 0.7, 0.0) | 4 (0.2, 0.6, 0.2) | 6 (0.25, 0.5, 0.25) | 5 (0.4, 0.5, 0.1) |
| Maneuver Warfare | 7 (0.33, 0.34, 0.33) | 6 (0.3, 0.4, 0.3) | 5 (0.2, 0.7, 0.1) | 7 (0.2, 0.6, 0.2) | 5 (0.1, 0.5, 0.4) |
| Ambush/ Envelopment | 6 (0.1, 0.7, 0.3) | 7 (0.1, 0.6, 0.3) | 7 (0.2, 0.8, 0.0) | 7 (0.1, 0.5, 0.4) | 6 (0.1, 0.7, 0.2) |
| Peace Keeping/ Enforcement | 5 (0.2, 0.4, 0.4) | 4 (0.2, 0.6, 0.2) | 3 (0.2, 0.6, 0.2) | 6 (0.4, 0.6, 0.0) | 7 (0.4, 0.5, 0.1) |

NOTE: The median m and probability distribution (P[m-1], P[m], P[m+1]) are shown in each cell. A higher value on the 1-to-9 rating scale indicates a more positive level of the characteristic.

## Air + SOF

This option augments the air only force with a limited ground element, in the form of SOF teams that conduct reconnaissance and surveillance, and assist with target acquisition, confirmation and damage assessment (SOF-RST). These teams support a balanced air and missile element that includes two companies of AH-64D helicopters, a full air expeditionary force, with both A-10s and TAC-AIR, and as many NTACMS as the heavy option. The SOF-RST teams are very strong on transportability, stealth and self-sufficiency, since they are so light and well-trained, but are extremely weak on mobility, firepower and protection because they are dismounted and have only basic weapons for personal defense. Their strengths, however, compensate for the weaknesses of the force's air element on stealth and self-sufficiency, but may pull down its overall levels of mobility, firepower and protection to some degree. But, the real benefit of these

teams is that, because of the ground information they provide, they allow the air + SOF option to use the better of the two standoff concepts. Indeed, standoff (with ground information) is most superior to standoff (no ground information) on its three worst characteristics: awareness, adaptability and economy.

## 5.3 "REVOLUTIONARY" OPTIONS FOR THE FAR TERM (2015 – 2025)

This section describes the five far-term force options, and discusses the characteristics of their system and operational components. As in the case of the near-term options, detailed information regarding the composition of the far-term options, and their components' characteristics, is provided in four tables. Table 5.8 indicates the role played by each system, and the quantity included in every option, while Table 5.9 shows how often the operational concepts are used by each option. Tables 5.10 and 5.11 show the characteristic rating distributions for the far-term systems and concepts, respectively.[54]

### Lean Heavy

The lean heavy option is a trimmed-down, more advanced version of the near-term heavy force. The current versions of the Abrams and Bradley are replaced with notional next-generation variants, the M1A3 and M2A4, which incorporate significant improvements in both firepower and protection. The M1A3 has a 140mm main gun, as compared to the 120mm gun on the M1A2, and a combination of sophisticated heavy armor and an advanced active protection system (APS) that together protect it against most antitank weapons, including those with top-attack munitions, and even some kinetic energy weapons. The M2A4 includes an upgrade from a 25mm to a 50mm gun, and a much better ATGM in the form of the Follow-on-to-TOW (FOTT), as well as advanced reactive armor and a suite of defensive aids to protect it against most types of ATGM. The FOG-M version of the Bradley (M2A4-FGM) and the new MLRS are

improved versions of their near-term counterparts, with slightly more protection and stealth because they both have better armor and a lower signature. The far-term MLRS also uses ATACMS, which improves its firepower and allows it to play an indirect fire far (rather than close) role in the force.

**Table 5.8**

**Roles and Quantities of Systems in Far-Term Force Options**

| | | Quantity, by Force Option | | | | |
|---|---|---|---|---|---|---|
| **System** | **Role*** | Lean Heavy | Future Medium | Enhanced Light | Advanced Air Only | Advanced Air + SOF |
| M1A3 | 1 | 40 | 0 | 0 | 0 | 0 |
| M2A4 | 2 | 40 | 0 | 0 | 0 | 0 |
| M2A4-FGM | 3 | 12 | 0 | 0 | 0 | 0 |
| Crusader | 3 | 24 | 0 | 0 | 0 | 0 |
| MLRS | 4 | 6 | 0 | 0 | 0 | 0 |
| FSCS | 7 | 8 | 0 | 0 | 0 | 0 |
| FCS-DFV | 1 | 0 | 28 | 0 | 0 | 0 |
| FCS-IFV | 2 | 0 | 30 | 0 | 0 | 0 |
| FCS-APC | 2 | 0 | 28 | 0 | 0 | 0 |
| FCS-ART | 3 | 0 | 8 | 0 | 0 | 0 |
| FCS-REC | 7 | 0 | 10 | 0 | 0 | 0 |
| ARES | 3 | 0 | 12 | 0 | 0 | 0 |
| Adv. MLRS | 4 | 0 | 6 | 0 | 0 | 0 |
| AHMV-FOT | 2 | 0 | 0 | 28 | 0 | 0 |
| AHMV-APC | 2 | 0 | 0 | 14 | 0 | 0 |
| RST-V | 7 | 0 | 0 | 14 | 0 | 0 |
| Adv. Javelin | 2 | 0 | 0 | 24 | 0 | 0 |
| Adv. Mortar | 3 | 0 | 0 | 16 | 0 | 0 |
| Small AFSS | 3 | 0 | 0 | 36 | 0 | 36 |
| Large AFSS | 4 | 0 | 0 | 18 | 0 | 18 |
| AH-64D+ | 5 | 18 | 18 | 0 | 0 | 18 |
| RAH-66 | 8 | 9 | 9 | 9 | 18 | 9 |
| Adv. TAC-AIR | 6 | 72 | 36 | 16 | 72 | 72 |
| Adv. NTACMS | 6 | 18 | 12 | 6 | 18 | 18 |
| SOF-RST | 9 | 0 | 0 | 0 | 0 | 20 |
| SOF-AST | 9 | 0 | 0 | 0 | 0 | 20 |

* - Key for system roles: (1) direct fire attack, (2) direct fire support, (3) indirect fire close, (4) indirect fire far, (5) close air support, (6) deep air interdiction, (7) reconnaissance scout, (8) reconnaissance attack, (9) special operations.

[54] Tables 4.5 and 4.7 define the levels of these rating scales.

The lean heavy force also includes two new vehicles that are currently in development: the Crusader self-propelled howitzer, and the Future Scout and Cavalry System (FSCS). Crusader provides higher levels of mobility, protection, self-sufficiency, and firepower than Paladin because it is faster, has better armor, is more efficient and independent, and has a higher rate of fire with more accuracy. But, Crusader and its re-supply vehicle are together much less transportable than Paladin due to their larger size and weight (Matsumura, Steeb and Gordon, 1998). The FSCS is a new type of reconnaissance vehicle that plays a scout role in this force. In some sense, the FSCS replaces the M3A3 Bradley cavalry vehicle, providing much more stealth, due to its lower profile and signature, and slightly better transportability, mobility and self-sufficiency, because it is lighter, faster and more efficient. It does, however, have somewhat less firepower and protection; to avoid drawing added attention, it only has a 35mm gun for self-defense, and it has less armor to keep its weight down.

The air component of the lean heavy force includes the following systems: a future version of the Apache Longbow attack helicopter (AH-64D+), the Comanche reconnaissance attack helicopter (RAH-66), advanced TAC-AIR[55], and an advanced version of NTACMS. Because of its sleek design, and its use of lighter, stronger materials and other technological advances, the RAH-66 has slightly higher levels of stealth, protection, transportability, and self-sufficiency than the AH-64D+. It does, however, have a bit less firepower because it carries fewer missiles. A third of the attack helicopters in the lean heavy force are RAH-66s, which play a reconnaissance attack role, while the other two thirds are AH-64D+s, which play a close air support role. The force also includes a full wing of 72 advanced TAC-AIR, along with an allotment of 18 advanced NTACMS, both still in a deep air interdiction role. Due to incremental technological

---

[55] These aircraft are all ground-attack versions of the Joint Strike Fighter (JSF), since it is assumed that the A-10 will have been phased out by 2015.

improvements, these two systems are both slightly better, across the board, than their near-term versions.

**Table 5.9**

**Mix of Operational Concepts Used by Far-Term Force Options**

| | Proportion of Use, by Force Option | | | | |
|---|---|---|---|---|---|
| **Operational Concept** | Lean Heavy | Future Medium | Enhanced Light | Advanced Air Only | Advanced Air + SOF |
| Standoff (no ground info) | 0 | 0 | 0 | 1 | 0 |
| Standoff (w/ ground info) | 0.143 | 0.286 | 0.3 | 0 | 0.75 |
| Maneuver Warfare | 0.571 | 0.286 | 0 | 0 | 0 |
| Ambush/ Envelopment | 0.143 | 0.286 | 0.2 | 0 | 0.25 |
| Peace Keeping/ Enforcement | 0.143 | 0.143 | 0.5 | 0 | 0 |

The lean heavy force uses the same operational concepts, in the same proportions, as the near-term heavy force. The characteristics of these concepts, however, improve substantially between the two time frames. In particular, the maneuver warfare concept, which is used most often, is better across all characteristics, with its largest gains in adaptability and ability to support. These improvements are attributable to the extensive use of advanced information technologies to facilitate intelligence filtering, target classification, decision making, virtual training, decentralized control, and real-time logistics.

### Future Medium

The future medium force option is, like its near-term counterpart, built around a single vehicle platform. Five different versions of this vehicle—the future combat system (FCS)—are included in the force. All of the FCS variants have fairly high levels of transportability, mobility, stealth and self-sufficiency. These levels exceed those of the M1A2 and the M2A3/M3A3 because the FCS is lighter, smaller, faster, and more efficient than these contemporary fighting vehicles. The FCS-DFV, which plays a direct fire attack role, has an advanced

hypervelocity missile system, sophisticated armor and a robust APS that give it almost as much firepower and protection as the M1A2 , but at a much lower weight.[56] Both the FCS-IFV and the FCS-APC play a direct fire support role in the force, and have a similar level of protection. The main armament of the FCS-IFV is a FOTT ATGM, so it has slightly less firepower than the FCS-DFV, and is a bit more stealthy, since its behavior is less conspicuous. The FCS-APC has even more stealth for the same reason, but because it only has a 30-mm gun for self-defense, it has much less firepower. A self-propelled howitzer/mortar version, the FCS-ART, provides considerable firepower in an indirect fire close role, and has about as much stealth as the FCS-IFV, but a bit less protection, since it only has smart armor for top-attack threats, and no APS. A reconnaissance scout role is played by the FCS-REC, which is as stealthy as the FCS-APC, but has slightly more firepower, even though it has the same gun, because its targeting system allows it to fire at a higher rate and with greater accuracy. The bulk of the FSC vehicles in the future medium force are DFV, IFV and APC versions, each in about equal numbers, with ART and REC versions making up the remainder.

The future medium force also includes two other types of vehicles: an Advanced Robotic Engagement System (ARES) and an advanced MLRS. The ARES , which is essentially a remote-control missile pod, provides substantial firepower in an indirect fire close role. Because it is efficient, light, small and fairly quick, this robotic vehicle is highly self-sufficient and transportable, and quite stealthy and mobile as well. It is not armored, however, so it has very poor protection (although this may be less important since it is unmanned). The advanced MLRS is a light-weight, wheeled missile system that plays an indirect fire far role. Its characteristics are similar to those of the ARES, but it has a bit

--------

[56] Estimates of the combat weight of an FCS vehicle range from 40-45 tons (Sharoni and Bacon, 1997) to as low as 20-25 tons, as compared to the M1A2 which weighs in at 65-70 tons.

more mobility and protection because it is manned, which also makes it a little less self-sufficient.[57]

The mix of systems in the air component of the future medium force is similar to that of the lean heavy force. This option, however, includes only half as many advanced TAC-AIR and two thirds as many advanced NTACMS. Since it has to respond to crises more quickly than the lean heavy force, the future medium force will have fewer aircraft and missiles at its disposal, relying primarily on pre-deployed air and sea power.

The future medium option uses a slightly different mix of operational concepts than the near-term medium force, placing equal emphasis on maneuver warfare, standoff (with ground information), and ambush/envelopment, and only half as much on peace keeping/enforcement. Standoff (with ground information) is better in the far term than in the near term on every characteristic because it uses advanced sensor and communication technologies to improve the accuracy of long-range weapons, and the acquisition, classification and selection of targets. The coordination of this concept, in fact, improves to a level that even surpasses that of maneuver warfare in the far term, since it uses information technology to greatly increase the speed at which decisions are made, conveyed and implemented. The ambush/envelopment concept improves even more dramatically between the two time frames; every characteristic except ability to support increases to the top level on its rating scale. This concept rates so highly because it takes even greater advantage of the technological advances used by

---

[57] Unmanned robotic vehicles are generally less mobile than manned vehicles because they have to be driven either remotely or by an autonomous program. If the vehicle is driven remotely, as is the case with the ARES, the operator will not have the same range of sensory inputs that an on-board driver would have. As a result, his reaction times will be longer, and he is more likely to make mistakes, so he will have to drive slower and more carefully, thereby reducing the effective mobility of the vehicle. An autonomous program would have great difficulty making even routine driving decisions, like choosing a route to avoid an obstacle, so the mobility of an autonomous vehicle would be reduced even more severely. Such programs are notoriously bad at replicating adaptive human behavior, so they have to proceed very slowly to give themselves enough time and room to correct the errors they will inevitably make.

the other far-term concepts; its flexibility, decentralization and focus allow it to benefit extensively from improvements in training, intelligence, communications, planning, decision aids, and targeting.

### Enhanced Light

The enhanced light force includes three types of vehicle systems: ATGM and APC versions of an Advanced High-Mobility Vehicle (AHMV), which both play a direct fire support role, and a small, light-weight Reconnaissance, Surveillance and Targeting Vehicle (RST-V)[58] in a reconnaissance scout role. Both versions of the AHMV are better protected and more mobile, stealthy and self-sufficient than a HMMWV because of their light-weight armor, defensive aids, lower signature, and greater efficiency. The FOT version of the AHMV, with a FOTT ATGM on board, even provides a moderate amount of firepower. The RST-V has very little firepower or protection, as it has no armor and only a small gun, but rates higher on transportability, mobility, stealth and self-sufficiency than the AHMV, since it is even lighter, faster, smaller, more elusive and more efficient. This mix of capabilities reflects the nature of the RST-V's job, which is not to fight, but rather to get in quickly, hide, provide valuable information, and then get out safely.

Thee light force also includes substantial numbers of infantry teams and unmanned missile pods. Advanced dismounted Javelin and mortar teams both provide about the same firepower and excellent transportability as their near-term versions, and are even more stealthy and self-sufficient, due to improved training, camouflage and weapon materials. These teams still, however, have no vehicles, and therefore very little mobility or protection. Small and large

--------

[58] The RST-V is a prototype vehicle developed by the Defense Advanced Research Projects Agency (DARPA). Detailed information about the RST-V is available at: http://www.darpa.mil/tto/Programs/rst.html, last accessed January 24, 2000.

versions of the Advanced Fire Support System (AFSS)[59] play indirect fire close and far roles, respectively, in the enhanced light force. Both types of AFSS are unmanned, remote-control missile launchers—"missiles in a box"—that can be air-dropped onto the battlefield. Once deployed, however, they have no mobility and very little protection, but are quite stealthy and extremely self-sufficient, since they simply hide, without moving, until they are used. The large AFSS provides slightly more firepower than the small version, but is much less transportable because of its substantially higher weight.

This enhanced light option has a much smaller air component than the future medium force. It has the same number of RAH-66 helicopters for reconnaissance attack, but does not have any AH-64D+s for close air support. Also, it also has only half as many advanced NTACMS, and fewer than half as many advanced TAC-AIR, for deep air interdiction. The air component of this option is small because it must respond quickly to defuse an emerging crisis, or enforce a new peace accord, so it can only rely on air and sea power that is already deployed in the region.

This force uses the peace keeping/enforcement operational concept half of the time, placing a bit more of its remaining emphasis on standoff (with ground information) and a bit less on ambush/envelopment. In the far term, the peace keeping/enforcement concept rates higher than in the near term on every characteristic, with substantial improvements in awareness, coordination and especially adaptability, bringing every rating up to a moderate or high level. These improvements, like those in all of the other far-term concepts, are attributable to the application of a broad range of advanced technologies, but also incorporate lessons learned form peace operations in the intervening period.

---

[59] The AFSS is a prototype system developed by DARPA. Detailed information about AFSS is available at: http://www.darpa.mil/tto/Programs/afs.html, last accessed January 24, 2000.

## Table 5.10

## Characteristic Ratings of Far-Term Systems

| System | System Characteristics | | | | | |
|---|---|---|---|---|---|---|
| | Transport-ability | Mobility | Firepower | Protection | Stealth | Self-sufficiency |
| M1A3 | 2 (0.0, 1.0, 0.0) | 4 (0.2, 0.5, 0.3) | 9 (0.0, 1.0, 0.0) | 7 (0.4, 0.5, 0.1) | 1 (0.0, 0.6, 0.4) | 3 (0.1, 0.8, 0.1) |
| M2A4 | 4 (0.4, 0.6, 0.0) | 4 (0.0, 0.7, 0.3) | 6 (0.2, 0.8, 0.0) | 5 (0.2, 0.6, 0.2) | 2 (0.0, 0.6, 0.4) | 4 (0.2, 0.7, 0.1) |
| M2A4-FGM | 4 (0.2, 0.8, 0.0) | 4 (0.0, 0.7, 0.3) | 8 (0.0, 1.0, 0.0) | 3 (0.3, 0.6, 0.1) | 3 (0.3, 0.7, 0.0) | 4 (0.1, 0.8, 0.1) |
| Crusader | 1 (0.0, 0.6, 0.4) | 4 (0.0, 0.8, 0.2) | 7 (0.2, 0.8, 0.0) | 3 (0.3, 0.6, 0.1) | 3 (0.0, 0.7, 0.3) | 4 (0.4, 0.5, 0.1) |
| MLRS | 4 (0.0, 0.8, 0.2) | 4 (0.0, 0.6, 0.4) | 7 (0.3, 0.7, 0.0) | 3 (0.3, 0.6, 0.1) | 3 (0.0, 0.7, 0.3) | 4 (0.1, 0.8, 0.1) |
| FSCS | 5 (0.2, 0.8, 0.0) | 5 (0.1, 0.7, 0.2) | 4 (0.0, 1.0, 0.0) | 3 (0.3, 0.6, 0.1) | 5 (0.1, 0.6, 0.3) | 5 (0.1, 0.7, 0.2) |
| FCS-DFV | 5 (0.4, 0.6, 0.0) | 6 (0.3, 0.6, 0.1) | 7 (0.33, 0.34, 0.33) | 6 (0.2, 0.7, 0.1) | 4 (0.3, 0.7, 0.0) | 6 (0.1, 0.8, 0.1) |
| FCS-IFV | 5 (0.3, 0.7, 0.0) | 6 (0.2, 0.7, 0.1) | 6 (0.2, 0.8, 0.0) | 6 (0.4, 0.6, 0.0) | 5 (0.2, 0.6, 0.2) | 6 (0.1, 0.7, 0.2) |
| FCS-APC | 5 (0.1, 0.9, 0.0) | 6 (0.2, 0.7, 0.1) | 2 (0.0, 0.6, 0.4) | 6 (0.3, 0.7, 0.0) | 6 (0.4, 0.5, 0.1) | 6 (0.1, 0.6, 0.3) |
| FCS-ART | 5 (0.2, 0.8, 0.0) | 6 (0.2, 0.7, 0.1) | 6 (0.0, 0.7, 0.3) | 5 (0.1, 0.6, 0.3) | 5 (0.4, 0.6, 0.0) | 6 (0.1, 0.7, 0.2) |
| FCS-REC | 5 (0.0, 0.8, 0.2) | 6 (0.2, 0.6, 0.2) | 3 (0.4, 0.6, 0.0) | 5 (0.2, 0.6, 0.2) | 6 (0.4, 0.5, 0.1) | 6 (0.1, 0.5, 0.4) |
| ARES | 7 (0.4, 0.6, 0.0) | 5 (0.5, 0.4, 0.1) | 7 (0.2, 0.6, 0.2) | 1 (0.0, 0.9, 0.1) | 5 (0.33, 0.34, 0.33) | 7 (0.2, 0.4, 0.4) |
| Adv. MLRS | 7 (0.2, 0.8, 0.0) | 6 (0.4, 0.5, 0.1) | 7 (0.3, 0.4, 0.3) | 2 (0.3, 0.7, 0.0) | 5 (0.4, 0.6, 0.0) | 6 (0.1, 0.5, 0.4) |
| AHMV-FOT | 7 (0.0, 0.8, 0.2) | 6 (0.4, 0.4, 0.2) | 5 (0.0, 0.8, 0.2) | 3 (0.3, 0.7, 0.0) | 6 (0.3, 0.7, 0.0) | 7 (0.1, 0.8, 0.1) |
| AHMV-APC | 7 (0.0, 0.8, 0.2) | 6 (0.2, 0.4, 0.4) | 2 (0.0, 1.0, 0.0) | 3 (0.4, 0.6, 0.0) | 6 (0.2, 0.6, 0.2) | 7 (0.1, 0.7, 0.2) |
| RST-V | 8 (0.3, 0.7, 0.0) | 7 (0.4, 0.6, 0.0) | 2 (0.3, 0.4, 0.3) | 1 (0.0, 0.7, 0.3) | 7 (0.4, 0.6, 0.0) | 7 (0.1, 0.5, 0.4) |
| Adv. Javelin | 9 (0.0, 1.0, 0.0) | 1 (0.0, 0.9, 0.1) | 5 (0.0, 1.0, 0.0) | 1 (0.0, 0.9, 0.1) | 8 (0.1, 0.8, 0.1) | 8 (0.0, 0.7, 0.3) |
| Adv. Mortar | 9 (0.0, 1.0, 0.0) | 1 (0.0, 0.9, 0.1) | 6 (0.0, 0.7, 0.3) | 1 (0.0, 0.9, 0.1) | 8 (0.1, 0.8, 0.1) | 8 (0.0, 0.8, 0.2) |
| Small AFSS | 7 (0.2, 0.6, 0.2) | 1 (0.0, 1.0, 0.0) | 6 (0.3, 0.6, 0.1) | 1 (0.0, 1.0, 0.0) | 7 (0.2, 0.6, 0.2) | 9 (0.1, 0.9, 0.0) |
| Large AFSS | 4 (0.3, 0.7, 0.0) | 1 (0.0, 1.0, 0.0) | 7 (0.2, 0.6, 0.2) | 1 (0.0, 1.0, 0.0) | 7 (0.3, 0.6, 0.1) | 9 (0.3, 0.7, 0.0) |
| AH-64D+ | 7 (0.2, 0.6, 0.2) | 8 (0.3, 0.7, 0.0) | 6 (0.0, 0.6, 0.4) | 2 (0.0, 0.6, 0.4) | 5 (0.2, 0.4, 0.4) | 1 (0.0, 0.7, 0.3) |

| System | System Characteristics Transport-ability | Mobility | Firepower | Protection | Stealth | Self-sufficiency |
|---|---|---|---|---|---|---|
| RAH-66 | 8 (0.3, 0.6, 0.1) | 8 (0.2, 0.8, 0.0) | 6 (0.2, 0.6, 0.2) | 3 (0.4, 0.6, 0.0) | 6 (0.4, 0.5, 0.1) | 2 (0.3, 0.7, 0.0) |
| Adv. TAC-AIR | 9 (0.1, 0.9, 0.0) | 9 (0.0, 1.0, 0.0) | 7 (0.2, 0.5, 0.3) | 3 (0.2, 0.8, 0.0) | 8 (0.4, 0.5, 0.1) | 1 (0.0, 0.6, 0.4) |
| Adv. NTACMS | 8 (0.1, 0.5, 0.4) | 4 (0.3, 0.5, 0.2) | 8 (0.4, 0.6, 0.0) | 1 (0.0, 0.9, 0.1) | 8 (0.1, 0.5, 0.4) | 7 (0.1, 0.5, 0.4) |
| SOF-RST | 9 (0.2, 0.8, 0.0) | 1 (0.0, 0.6, 0.4) | 1 (0.0, 0.8, 0.2) | 1 (0.0, 0.9, 0.1) | 9 (0.2, 0.8, 0.0) | 9 (0.2, 0.8, 0.0) |
| SOF-AST | 9 (0.4, 0.6, 0.0) | 1 (0.0, 0.8, 0.2) | 4 (0.3, 0.1, 0.6) | 1 (0.0, 0.9, 0.1) | 9 (0.4, 0.6, 0.0) | 9 (0.4, 0.6, 0.0) |

NOTE: The median m and probability distribution (P[m-1], P[m], P[m+1]) are shown in each cell. A higher value on the 1-to-9 rating scale indicates a more positive level of the characteristic.

### Advanced Air Only

The advanced air only option includes the same number of advanced TAC-AIR and NTACMS as the lean heavy option. The composition of this air only option differs from its near-term version, however, because it includes a fairly large number of RAH-66 helicopters—twice as many as in the other far-term options. The RAH-66 can participate in this type of force because, unlike the AH-64D+, it can conduct some operations without direct ground support.

Since it has no access to ground information, the far-term air only option still uses the standoff (no ground information) concept exclusively. This concept is, however, somewhat better in the far term than in the near term. Every characteristic is rated higher, with coordination and adaptability gaining substantially, due to better communications, decision support and training, as well as changes in culture to accommodate strict rules of engagement.

### Advanced Air + SOF

The advanced air + SOF option consists of three components: air power and naval missiles; robotic ground-based missiles; and multi-purpose SOF teams. This option includes the same air component as the lean heavy force, consisting of exactly the same numbers of AH-64D+, RAH-66, advanced TAC-AIR, and

advanced NTACMS. The force also has as many small and large AFSS as the enhanced light force, which give it a very responsive indirect fire capability. The ground-presence element of this option consists of an equal number of two types of SOF teams: RST teams that include a mix of human and robotic elements; and assault and sabotage (AST) teams that can attack selected targets in enemy territory. Because they are so light, inconspicuous and independent, both types of SOF teams have the highest ratings possible for transportability, stealth and self-sufficiency, but extremely low ratings for mobility and protection. The two types, of course, have different levels of firepower: AST teams have some hand-held ATGMs, while RST teams only have personal weapons.

Unlike the near-term air + SOF option, this far-term version does not rely exclusively on standoff (with ground information); it also uses another concept, ambush/envelopment, about a quarter of the time. The inclusion of SOF-AST teams in this far-term option enable it to use the ambush/envelopment concept occasionally. Since this concept is rated so highly, for reasons discussed earlier, using it instead of standoff (with ground information), even if only part of the time, will improve the overall effectiveness of the advanced air + SOF option.

**Table 5.11**

**Characteristic Ratings of Far-Term Operational Concepts**

| | Operational Characteristic | | | | |
|---|---|---|---|---|---|
| **Operational Concept** | Awareness | Coordination | Adaptability | Economy | Ability to Support |
| Standoff (no ground info) | 5 (0.1, 0.7, 0.3) | 7 (0.3, 0.7, 0.0) | 4 (0.3, 0.6, 0.1) | 5 (0.4, 0.6, 0.0) | 6 (0.1, 0.5, 0.4) |
| Standoff (w/ ground info) | 7 (0.0, 0.6, 0.4) | 8 (0.2, 0.7, 0.1) | 5 (0.0, 0.8, 0.2) | 7 (0.1, 0.5, 0.4) | 6 (0.2, 0.6, 0.2) |
| Maneuver Warfare | 8 (0.33, 0.34, 0.33) | 7 (0.33, 0.34, 0.33) | 7 (0.4, 0.6, 0.0) | 8 (0.3, 0.6, 0.1) | 7 (0.4, 0.6, 0.0) |
| Ambush/ Envelopment | 9 (0.4, 0.6, 0.0) | 9 (0.4, 0.6, 0.0) | 9 (0.4, 0.6, 0.0) | 9 (0.4, 0.6, 0.0) | 7 (0.2, 0.7, 0.1) |
| Peace Keeping/ Enforcement | 7 (0.3, 0.6, 0.1) | 6 (0.1, 0.6, 0.3) | 6 (0.4, 0.6, 0.0) | 7 (0.4, 0.6, 0.0) | 8 (0.4, 0.5, 0.1) |

NOTE: The median m and probability distribution (P[m-1], P[m], P[m+1]) are shown in each cell. A higher value on the 1-to-9 rating scale indicates a more positive level of the characteristic.

## 5.4 KEY OPTION COMPARISONS

This section presents several key comparisons of the effectiveness of selected pairs of force options. Each comparison involves two options from the same time frame that are similar with respect to one of two important factors: reach, responsiveness and flexibility; or effective ground presence. These factors address substantive questions of military capability—where can the force operate? how quickly can it be deployed? what sorts of ground missions can it perform?—that affect how, and under what circumstances, a force option can be used by top-level decision makers. Two other important factors of a political nature are also considered: reduced risk of casualties; and organizational and budgetary stability. These two factors address the viability of an option—the political circumstances under which it could be used, and the bureaucratic obstacles it is likely to face. The options in each time frame are rated low, moderate or high on all four of these factors, as shown in Table 5.12 for the near term, and in Table 5.13 for the far term.

**Table 5.12**

**Important Factors for Near-Term Force Options**

| | Force Option | | | | |
|---|---|---|---|---|---|
| **Important Factors** | Heavy | Medium | Light | Air Only | Air + SOF |
| Reach, responsiveness and flexibility | low | moderate | high (–) | high | high |
| Effective ground presence | high | high | high | low | moderate |
| Reduced risk of casualties | high (–) | moderate | low | high | moderate |
| Organizational and budgetary stability | high | low | high | high | high (–) |

The following two subsections present the option comparisons that will be addressed in the two time frames. Each comparison—five in the near term, and five in the far term—is discussed in a brief paragraph that discusses how the options involved rate on the important military and political factors introduced

above. In each case, one of the two military factors has the same rating for both options, and the differences among the remaining factors are highlighted.

**Near Term**

*Medium-weight versus heavy armored.* The medium and heavy options both provide an effective ground presence—they are both rated "high" on this factor. The medium force has more reach, responsiveness and flexibility than the heavy force, since it can deploy more quickly to more places. But, it rates lower on reduced casualty risk and organizational and budgetary stability, because it is not as well-protected or as potent, and would require a significant amount of reorganization and new procurement. The larger issue, then, is whether the rapid, and reasonably potent, ground-force-projection capability provided by a medium-weight force is worth the associated political risks—force structure disruption and the potential for higher casualties.

*Medium-weight versus light infantry.* The light force, like the medium force, provides an effective ground presence. It is, of course, less potent than the medium force, so it entails a fairly high casualty risk (as indicated by its "low" rating on this factor). On the other hand, it requires less preparation time, lift and support, and can operate in a wider range of environments, so it has greater reach, responsiveness and flexibility. Also, since light forces are already a part of the current force structure, this option would not threaten organizational and budgetary stability, while developing a medium force clearly would. Thus, comparing these two ground force options provides some insight into what a new medium force can do relative to a contemporary light force, taking into account its greater survivability and any constraints on where and how fast it can be deployed. These capabilities can then be weighed against the overall cost of its introduction.

*Light infantry versus aircraft alone.* Both the light force and the air only force provide a high level of reach, responsiveness and flexibility, since they can be

deployed on fairly short notice to a wide range of locations. And, neither option involves any force structure changes, so they both rate highly on stability. Of course, the air only option has no ground element, so it cannot provide an effective ground presence like the light option does. But, the light force is not well-protected, so it is quite vulnerable, whereas the aircraft in the air only option use PGM and operate at a safe altitude to minimize their exposure to air defense threats. This question draws attention to the important tradeoff between having a ground presence and the casualty risks that this entails.

*Aircraft and SOF teams versus aircraft alone.* The air + SOF option and the air only option both have a high degree of reach, responsiveness and flexibility, and neither involves any significant threat to organizational and budgetary stability. The inclusion of SOF-RST teams in the air + SOF option enables it to provide some presence on the ground—a capability that the air only option lacks. These teams, however, are vulnerable if discovered, so using them does increase the risk of casualties. This comparison again involves a tradeoff between ground presence and casualty risks, though the stakes here are lower than in the light-versus-air-only case.

*Aircraft and SOF teams versus light infantry.* Both of these options provide considerable reach, responsiveness and flexibility, and do not involve a significant threat to stability. The light force provides more ground presence, but also involves higher casualty risks, since it is larger and more exposed than the air + SOF force. Thus, once more, the tradeoff being addressed pits ground presence against casualty risks.

### Far Term

*Future medium-weight versus lean heavy legacy.* The future medium and lean heavy options both provide an effective ground presence. Also, because they incorporate technological advances in vehicle protection, both options rate highly on reduced risk of casualties. The future medium force has more reach,

responsiveness and flexibility, but rates lower on organizational and budgetary stability, since replacing legacy heavy divisions with future medium ones would require a major change in force structure. Comparing the effectiveness of these two forces provides an indication of what could be gained from the development of a potent, strategically agile force, which can then be compared to the cost and disruption that it would incur.

**Table 5.13**

**Important Factors for Far-Term Force Options**

| | Force Option | | | | |
|---|---|---|---|---|---|
| **Important Factors** | Lean Heavy | Future Medium | Enhanced Light | Advanced Air Only | Advanced Air + SOF |
| Reach, responsiveness and flexibility | low | moderate | high | high | high |
| Effective ground presence | high | high | high | low | moderate |
| Reduced risk of casualties | high | high (–) | low | high | moderate |
| Organizational and budgetary stability | high | low | moderate | high | moderate |

*Future medium-weight versus enhanced light infantry.* The enhanced light and future medium forces both provide an effective ground presence. The enhanced light option is a bit less potent and much more vulnerable than the future medium option, so it has a much higher potential for casualties. But, it is more versatile and requires less time and effort to deploy, so its reach, responsiveness and flexibility rating is higher. Creating a far-term enhanced light force would require some force structure changes and technology investments, so it would pose a moderate threat to organizational and budgetary stability, but not as much as developing the future medium option would. These two ground forces offer a choice between a lower risk of casualties, but more disruption, and a bit more reach, responsiveness and flexibility.

*Enhanced light infantry versus advanced aircraft alone.* The enhanced light and advanced air only forces both have an equally high degree of reach,

responsiveness and flexibility. The enhanced light option involves some adjustments in force structure, while the advanced air only does not, so it has a lower stability rating. Also, because the air only force does not have a ground element, it has a much lower ground presence rating than the enhanced light option. The casualty risks associated with the enhanced light force, however, are relatively high compared to those of the advanced air only force. Thus, unlike the advanced air only force, the enhanced light option can provide an effective ground presence, but would also incur higher casualty risks and create more disruption.

*Advanced aircraft and SOF teams versus advanced aircraft alone.* The advanced air + SOF and air only options both have "high" ratings for reach, responsiveness and flexibility. The development of an advanced air + SOF force would, however, pose a moderate threat to budgetary stability, since it would require some significant technology investments. Unlike the advanced air only force, the advanced air + SOF option provides a considerable ground presence with two types of SOF teams. These teams are, however, quite vulnerable, so the casualty risks of this option are a bit higher than those of the air only option. Thus, shifting from advanced air only to advanced air + SOF increases ground presence, but incurs higher casualty risks and poses some threat to stability.

*Advanced aircraft and SOF teams versus enhanced light infantry.* Both of these options provide a high level of reach, responsiveness and flexibility, and pose a moderate threat to stability because of the technology investments they require. The enhanced light force, of course, provides a greater ground presence, but it also has higher casualty risks than the advanced air + SOF option, since light troops are more vulnerable than SOF teams. Thus, as in the near term, the primary tradeoff here is between ground presence and casualty risks.

## 5.5 CONCLUDING REMARKS

This chapter described the structure of the analysis that is presented in the following chapters, and provided the details on the composition and component characteristics of the options that are considered in this analysis. It also suggested a number comparisons between certain key pairs of options, which will be made once their effectiveness has been evaluated. Chapter 6 begins the presentation of the analysis by describing the results of the initial preparation phase of the HIMAX process.

# 6. PREPARATION

The preparation phase of the HIMAX process includes customization as a preliminary step, since it defines the dimensions of the evaluation model, and dictates what sorts of inputs are needed to determine the model's parameters. The remainder of this phase relies on expert choices and assessments to determine four sets of inputs for the evaluation model: (1) value functions assigned to each characteristic, (2) attribute contributions to force effectiveness in each mission, (3) characteristic contributions to each attribute, and (4) importance of system characteristics for each system role. For each set, this chapter presents and discusses the input selections and values used in the analysis, and how they were derived from the responses of the participating experts. (Appendix B provides biographical information on these experts.)

## 6.1 CHARACTERISTIC VALUE FUNCTION ASSIGNMENTS

The value functions that the evaluation model uses for each characteristic, in the near and far terms, are shown in Table 6.1. These assigned functions are the ones the experts selected most often for each characteristic. This table shows how many of the eight experts chose these functions, and the total number of different functions that at least one of them selected. If the latter is high and the former is low—the experts picked many different functions, and few chose the most popular one—then there was poor agreement on which function to use, and the corresponding row of Table 6.1 is shaded. In fact, there was a tie for the most frequently chosen function for three characteristics: transportability, firepower, and protection. In these cases, which are marked by an asterisk in Table 6.1, the model uses the function that would be preferred by more of the other experts.[60]

--------

[60] The convex and convex/cave functions ware both selected for transportability by two experts. Convex/cave was chosen because the remaining four experts would all prefer it. They

The impact of using each of these tied functions instead of the baseline selection is examined later in the exploration phase, which is presented in Chapter 10.

**Table 6.1**

**Value Functions Assigned to Each Characteristic, and the Degree of Agreement among the Experts on these Selections**

| Characteristic | Value Function Used in Analysis | Number of Experts Who Selected This Value Function | Total Number of Different Value Functions Selected |
|---|---|---|---|
| *System* | | | |
| Transportability | Convex/cave* | 2 | 6 |
| Mobility | Concave | 4 | 4 |
| Firepower | Linear* | 3 | 4 |
| Protection | Linear* | 2 | 5 |
| Stealth | Convex | 3 | 5 |
| Self-sufficiency | Linear | 5 | 3 |
| *Operational* | | | |
| Awareness | Convex/cave | 5 | 3 |
| Coordination | Convex/cave | 4 | 3 |
| Adaptability | Linear | 5 | 4 |
| Economy | Concave | 3 | 5 |
| Ability to Support | Linear | 3 | 4 |

NOTE: Shading indicates poor agreement among the eight experts regarding that selection.
* - At least one other function was selected by just as many of the experts.

The baseline value functions selections for each characteristic have some interesting implications. Four characteristics use the linear function: firepower, protection, adaptability, and ability to support. This choice indicates that the levels of these characteristics' scales[61] are equally spaced, so the marginal value of improvements is the same at every level. The choice of the concave function

selected linear, concave, concave/vex, and a custom function, all of which lie closer to convex/cave than to convex. For firepower, the convex function received three votes, just as many as the linear function. But, linear is used because the other two experts would prefer it, since they chose concave and convex/cave, both of which are closer to linear than to convex. Three functions were chosen by two experts each for protection: convex/cave, concave and linear. The remaining two experts picked convex and concave/vex. The expert who picked concave/vex would prefer linear over either of the other two functions, while the expert who picked convex would be indifferent between linear and convex/cave, but would prefer both of these to concave, so the tie-break goes to the linear function in this case. (To verify these comparisons, see the value function plots in Figure 3.3 of the Chapter 3.)

for mobility and economy implies that the marginal value of improving them is highest at the low end of their scales—a little bit of these two characteristics goes a long way. Only one characteristic, stealth, uses the convex function, which assigns increasing marginal value to successive scale levels. Thus, the greatest gains from improving stealth come to systems that are already quite stealthy. The s-shaped convex-cave function is assigned to transportability, awareness and coordination, so improvements in these characteristics are most valuable at moderate levels, but do not provide much added value at high or low levels.

## 6.2 ATTRIBUTE CONTRIBUTIONS TO EFFECTIVENESS

The experts assessed the importance of each attribute relative to every other for all six missions. The full array of attribute ratings (r[i,l,m]) used in the evaluation model was derived from their responses. The median response was selected for each comparison, and the following symmetry assumptions were applied: r[l,i,m]=1/r[i,l,m], and r[i,i,m]=1.[62] These ratings, which are shown in Table 6.2, yield the normalized attribute weights for each mission (X[i,m]) that are shown in Table 6.3.[63] The resulting weights, which are depicted in Figure 6.1, represent an implied consensus on the relative importance of the attributes in each mission.

There are clear differences across missions in the distribution of weight among the six force attributes. Lethality and ability to shock are the most important attributes for both halt and evict, reflecting the need to disrupt and disable enemy forces in these high-intensity missions. There are, however, some interesting differences between these two missions in terms of their emphasis on

---

[61] The nine-level rating scales for each system and operational characteristic are defined in Tables 4.5 and 4.7, respectively.

[62] If there is an even number of responses, the lower of the two middle ratings is used, rather than their mean. This ensures that the evaluation model uses an attribute rating that is on the appropriate rating scale; i.e., it is an integer or, if it is less than one, its reciprocal is an integer.

other attributes. In the offensive evict mission, as much weight is placed on survivability as on ability to shock, while survivability is less important in the defensive halt mission. Halt also requires more emphasis on transportability, and less on maneuverability and lethality, indicating a greater preference for responsiveness relative to fighting power.

Such parallels are less apparent among the other four missions; each has its own distinctive character in terms of which attributes are most important. The defend mission relies mostly on survivability and, to a lesser extent, lethality, which together account for almost half of the total weight. The remaining weight is distributed quite evenly, with a bit more on ability to shock and a bit less on maneuverability. The emphasis here on survivability is a bit surprising, given that light forces are often assigned defend-type missions, but it reflects the importance of avoiding losses in such situations. In protect, the other defensive mission, almost the same weight is placed on all six attributes, indicating that a robust, balanced force is favored in this type of mission, since equal weighting makes it more difficult for strong attributes to compensate for weaker ones. The raid mission emphasizes maneuverability the most, and relies on ability to shock and transportability much more than on lethality, survivability or sustainability. This distribution reflects the raid mission's focus on brief attacks that require surprise and quickness, rather than potency or endurance. Very little weight is placed on lethality or ability to shock in the stabilize mission, since they are less useful than other attributes in the peace operations where this mission would be prevalent. Survivability is especially important, given the proliferation of hand-held anti-tank weapons and the danger of ambush attacks. Maneuverability is also valuable because it enables a force to respond effectively to outbreaks of civil unrest or resistance. Deployability and sustainability are important because stabilize missions require a rapid response, followed by a lengthy occupation.

---

[63] The calculation of X[i,m] from r[i,l,m] is described in Chapter 3.

## Table 6.2

### Importance of Attributes Relative to Each Other, for Every Mission

| *Mission* / Importance of Attribute... | Deploy-ability | Lethality | Maneuver-ability | Ability to Shock | Surviv-ability | Sustain-ability |
|---|---|---|---|---|---|---|
| *Halt* | | | | | | |
| Deployability | 1 | 1 | 1 | **1** | **1** | 1 |
| Lethality | 1 | 1 | **3** | 1 | **1** | **3** |
| Maneuverability | 1 | **1/3** | 1 | 1/3 | **1** | **2** |
| Ability to Shock | **1** | 1 | 3 | 1 | 1 | 3 |
| Survivability | **1** | **1** | **1** | 1 | 1 | 2 |
| Sustainability | 1 | **1/3** | **1/2** | 1/3 | 1/2 | 1 |
| *Defend* | | | | | | |
| Deployability | 1 | 1 | 1 | 1/3 | 1/2 | 1 |
| Lethality | 1 | 1 | **3** | 1 | **1** | **2** |
| Maneuverability | 1 | **1/3** | 1 | 1/2 | 1/3 | 1 |
| Ability to Shock | 3 | 1 | 2 | 1 | **1/3** | 1 |
| Survivability | 2 | **1** | 3 | **3** | 1 | 2 |
| Sustainability | 1 | **1/2** | 1 | 1 | 1/2 | 1 |
| *Protect* | | | | | | |
| Deployability | 1 | **1** | 2 | 1 | 1 | 1 |
| Lethality | **1** | 1 | 1 | 1 | 1 | 1 |
| Maneuverability | 1/2 | 1 | 1 | 1 | 1 | 2 |
| Ability to Shock | 1 | 1 | 1 | 1 | 1/2 | 1 |
| Survivability | 1 | 1 | 1 | 2 | 1 | **1** |
| Sustainability | 1 | 1 | 1/2 | 1 | **1** | 1 |
| *Evict* | | | | | | |
| Deployability | 1 | 1/8 | 1/7 | 1/7 | **1/8** | **1** |
| Lethality | 8 | 1 | **3** | 1 | 1 | 3 |
| Maneuverability | 7 | **1/3** | 1 | 1 | **1** | 3 |
| Ability to Shock | 7 | 1 | 1 | 1 | 1 | 4 |
| Survivability | **8** | 1 | **1** | 1 | 1 | 3 |
| Sustainability | **1** | 1/3 | 1/3 | 1/4 | 1/3 | 1 |
| *Raid* | | | | | | |
| Deployability | 1 | 3 | 1 | 1 | 1 | 1 |
| Lethality | 1/3 | 1 | 1/2 | 1/2 | **2** | 5 |
| Maneuverability | 1 | 2 | 1 | 2 | **2** | 4 |
| Ability to Shock | 1 | 2 | 1/2 | 1 | 3 | **2** |
| Survivability | 1 | **1/2** | **1/2** | 1/3 | 1 | **2** |
| Sustainability | 1 | 1/5 | 1/4 | **1/2** | **1/2** | 1 |
| *Stabilize* | | | | | | |
| Deployability | 1 | 4 | 1 | 1/2 | 1/3 | 1 |
| Lethality | 1/4 | 1 | 1/3 | 1 | 1/2 | 1/3 |
| Maneuverability | 1 | 3 | 1 | 2 | 1 | 1 |
| Ability to Shock | 2 | 1 | 1/2 | 1 | 1/4 | 1/3 |
| Survivability | 3 | 2 | 1 | 4 | 1 | **1** |
| Sustainability | 1 | 3 | 1 | 3 | **1** | 1 |

NOTE: Shading indicates that experts' responses spanned 8 or more levels on the 1/9-to-9 scale, while the ratings with a response range of 4 or less are shown in **bold**.

The ratings used to calculate these attribute weights are the median values of the corresponding expert responses. The shaded cells in Table 6.2 indicate which ratings had a large range of responses from the experts (8 or more levels, out of 16), and those with a small range (4 or less) are shown in **bold**. The shading patterns reveal that, for each mission, the experts disagreed about the importance of certain clusters of attributes more than others. In the two high-intensity missions, halt and evict, the experts disagreed greatly on the importance of ability to shock relative to most of the other attributes. This attribute is among the most important for both missions, so these disagreements could have significant implications. There was fairly good agreement among the experts on the attribute ratings for the defend mission, although their opinions diverged markedly on a few that involved deployability, lethality or ability to shock—all attributes that are moderately important in this mission. There was, however, poor agreement on most of the ratings of deployability and ability to shock in the raid mission, for which both attributes are fairly important. In the protect mission, the greatest disagreements were for ratings that involved ability to shock or sustainability. All six attributes are about equally important for this mission, although the weights for these two are slightly lower than the others. The experts agreed the least about the ratings for the stabilize mission; there was a moderate or high range of responses (at least 6 levels) for every rating except that of survivability relative to sustainability (which had a range of just 2).

Overall, these attributes capture differences among the missions quite well; each one is more important than most of the others in at least one mission, and none of them are insignificant for any mission. Deployability is important for the raid and protect missions, but not for the evict mission, which emphasizes lethality more than any other mission. Maneuverability is more important than any other attribute in the raid mission, but is the least important attribute in the defense mission. Ability to shock is fairly important in most of the missions, but is not a dominant attribute in any of them. By contrast, survivability is the most

important attribute in two missions, defend and stabilize, and is fairly significant in all the others except raid. Sustainability is quite important in the stabilize mission, but is only a small or moderate contributor to every other mission.

**Table 6.3**

**Degree of Attribute Contributions to Force Effectiveness in Each Mission**

| | Proportion of Contribution, by Mission | | | | | |
|---|---|---|---|---|---|---|
| **Force Attribute** | Halt | Defend | Protect | Evict | Raid | Stabilize |
| Deployability | 0.1578 | 0.1152 | 0.1862 | 0.0345 | 0.1841 | 0.1422 |
| Lethality | 0.2276 | 0.2093 | 0.1659 | 0.2690 | 0.1487 | 0.0746 |
| Maneuverability | 0.1228 | 0.0959 | 0.1659 | 0.1824 | 0.2731 | 0.2050 |
| Ability to Shock | 0.2276 | 0.1743 | 0.1478 | 0.2298 | 0.2066 | 0.1005 |
| Survivability | 0.1772 | 0.2821 | 0.1862 | 0.2240 | 0.1137 | 0.2583 |
| Sustainability | 0.0869 | 0.1232 | 0.1478 | 0.0604 | 0.0738 | 0.2194 |

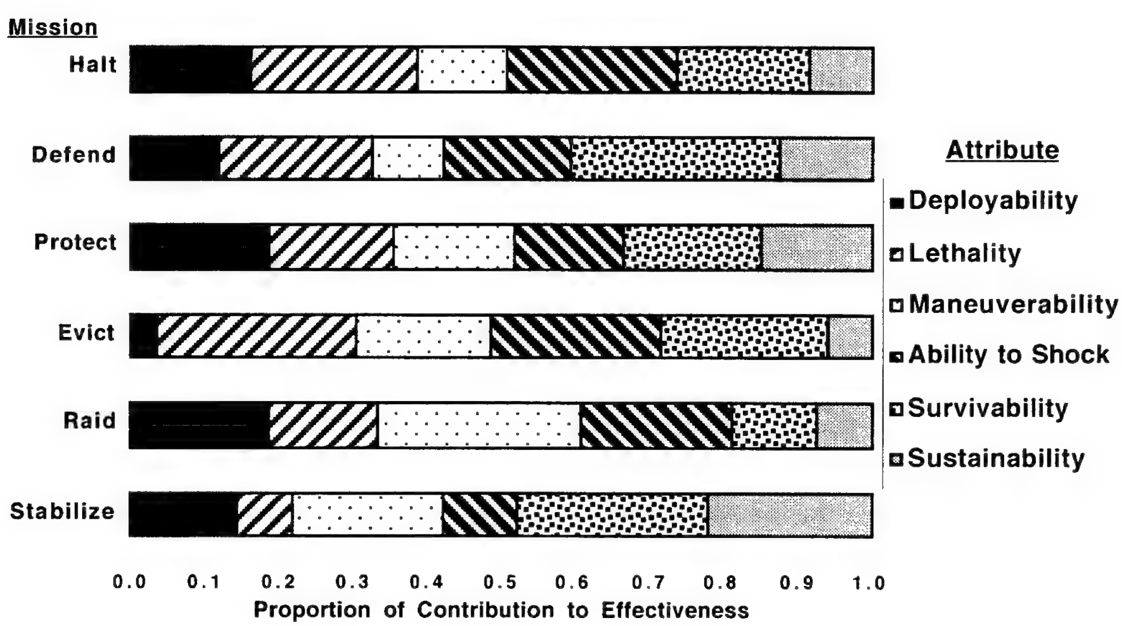



**Figure 6.1. Distribution of Attribute Contributions to Effectiveness in Each Mission**

## 6.3 CHARACTERISTIC CONTRIBUTIONS TO ATTRIBUTES

The same sets of normalized system and operational characteristic weights (Y[i,j] and Z[i,k], respectively) are used throughout the analysis to evaluate both near-term and far-term options. These weights quantify the overall contribution

that each characteristic makes to every force attribute. They are derived from ratings of each system and operational characteristic's main effect contribution (u[i,j] and v[i,k], respectively) and the synergistic contributions associated with interactions between them (w[i,j,k]).[64] The analysis uses the rating value that is the median of the corresponding expert assessments.[65] The main effect ratings are shown in Table 6.4, and the synergistic ratings are shown in Table 6.5. The resulting weights, which are normalized across all characteristics, are shown in Table 6.6, and depicted in Figure 6.2.

**Table 6.4**

**Direct Contributions to Attributes by Individual Characteristics**

| | Rating of Main Effect Contribution to Force Attribute | | | | | |
|---|---|---|---|---|---|---|
| **Characteristic** | Deploy-ability | Lethality | Maneuver-ability | Ability to Shock | Surviv-ability | Sustain-ability |
| *System* | | | | | | |
| Transportability | **9** | 0 | 2 | 2 | 0 | 4 |
| Mobility | 0 | **6** | **9** | 7 | **6** | 4 |
| Firepower | 0 | **9** | 3 | **8** | 6 | 0 |
| Protection | 0 | 5 | 5 | 5 | **9** | 1 |
| Stealth | 0 | 5 | 4 | 6 | **8** | 1 |
| Self-sufficiency | 4 | 3 | 4 | 3 | 4 | **9** |
| *Operational* | | | | | | |
| Awareness | 1 | **8** | 7 | 7 | **8** | 3 |
| Coordination | 5 | 7 | 5 | 7 | 7 | 3 |
| Adaptability | 3 | 6 | 5 | 5 | 6 | 5 |
| Economy | 5 | 5 | 3 | 6 | 7 | 7 |
| Ability to Support | 7 | 4 | 4 | 4 | 4 | **9** |

NOTE: Shading indicates that experts' responses spanned 7 or more levels on the 0-to-9 scale, while the ratings with a response range of 3 or less are shown in **bold**.

Before discussing the normalized characteristic weights, it is worth noting the patterns that exist in how much the experts agreed on the characteristic contribution ratings that these weights were derived from. The shaded cells in Tables 6.4 and 6.5 indicate which ratings were the most disputed, and those

---

[64] Chapter 3 explains how Y[i,j] and Z[i,k] are calculated from u[i,j], v[i,k] and w[i,j,k].

[65] If there is an even number of responses, the lower of the two middle ratings is used, rather than their mean, to ensure that the rating used by the evaluation model is an integer.

ratings that the experts strongly agreed on are shown in **bold**. The range of responses to the main effect ratings of transportability was quite large (at least 6) for every attribute except deployability. The experts agreed that transportability, by itself, was extremely important for deployability, but there was not a strong consensus on the extent of its direct contributions to any of the other attributes. All of the other characteristics had at least one direct attribute contribution rating that the experts strongly disagreed about, and there was moderate disagreement on most of the other ratings. The experts did, however, strongly agree on several ratings, in addition to the contribution of transportability to deployability, all of which had received the highest ratings for the attribute involved. In particular, there was a strong consensus on the ratings of mobility for three of the four dominance attributes: lethality, maneuverability, and survivability. The experts also agreed on the ratings of: firepower for lethality and ability to shock; protection and stealth for survivability; awareness for lethality and survivability; and self-sufficiency and ability to support for sustainability. These patterns of agreement represent relationships that are sensible, given the definitions of the attributes and characteristics, indicating that the experts understood these definitions and used the rating scales in a consistent manner.

There are a variety of interesting patterns of agreement among the experts on their synergistic contribution ratings for each attribute. Among the ratings for deployability, those involving interactions between transportability or self-sufficiency and any of the operational characteristics, except ability to support, had a large range of responses. There was a fairly strong consensus on most of the interactive contributions to lethality. In fact, the only strong agreement for any of the synergistic ratings were for the contributions of awareness and coordination in combination with mobility and firepower for lethality. The only large disagreements in these ratings for lethality were on several that involved firepower, protection, self-sufficiency, or economy. The degree of disagreement in the ratings for maneuverability was generally quite high, especially for those involving coordination, mobility or firepower. The interaction ratings for ability

to shock were also very contentious; the greatest disagreements were for ratings that involve self-sufficiency or adaptability, plus several others. The pattern in the interaction ratings for survivability are fairly subtle; there was a moderate level of agreement for all the ratings, especially those involving transportability and protection, with only a handful of ratings with slightly larger response ranges. There are, however, clear patterns in the interactive contributions to sustainability: the experts disagreed greatly on every rating involving transportability, mobility or economy.

The normalized weights assigned to each attribute, which are shown in Table 6.6 and depicted in Figure 6.2, reflect the consensus opinion among the experts on how important the characteristics are relative to one another. These aggregate opinions are quite plausible and consistent, in spite of significant disagreements among the experts about some of the underlying ratings. The relationship between these characteristic weights and the contribution ratings can be fairly obscure. To clarify the nature of these links, the contributions of the system characteristics to survivability are examined more closely here. Protection makes the largest contribution to survivability (over 12 percent), and stealth's contribution is the second largest (almost 11 percent). This is not surprising, since these two characteristics have the highest direct contribution ratings (9 and 8, respectively). Mobility and firepower have the next highest direct ratings (6), but firepower's contribution weight is a bit higher than that of mobility (9.1 versus 8.6 percent), because its ratings for synergistic interactions with operational characteristics are a full interval higher, on average (4.4 versus 3.4). The largest discrepancy was 4 intervals for these characteristics' interactions with economy; mobility had no synergy with economy (0), while firepower's was moderate to strong (4).

## Table 6.5

## Extra Synergistic Contributions to Attributes by Pairs of Characteristics

| *Attribute* **Operational→ System** | **Rating of Synergistic Contribution to Attribute by Pair of Characteristics** | | | | |
|---|---|---|---|---|---|
| | Awareness | Coordination | Adaptability | Economy | Ability to Support |
| *Deployability* | | | | | |
| Transportability | 1 | 6 | 5 | 5 | 7 |
| Mobility | 3 | 3 | 3 | 0 | 3 |
| Firepower | 0 | 0 | 0 | 2 | 1 |
| Protection | 0 | 0 | 0 | 0 | 0 |
| Stealth | 0 | 0 | 0 | 0 | 0 |
| Self-sufficiency | 1 | 3 | 4 | 5 | 9 |
| *Lethality* | | | | | |
| Transportability | 0 | 0 | 0 | 0 | 0 |
| Mobility | **6** | **6** | 5 | 3 | 3 |
| Firepower | **9** | **8** | 6 | 6 | 4 |
| Protection | 3 | 3 | 3 | 2 | 1 |
| Stealth | 6 | 4 | 3 | 0 | 0 |
| Self-sufficiency | 1 | 2 | 2 | 3 | 3 |
| *Maneuverability* | | | | | |
| Transportability | 0 | 0 | 1 | 0 | 0 |
| Mobility | 7 | 7 | 6 | 4 | 5 |
| Firepower | 7 | 6 | 3 | 1 | 1 |
| Protection | 4 | 3 | 3 | 0 | 0 |
| Stealth | 5 | 3 | 3 | 0 | 2 |
| Self-sufficiency | 3 | 3 | 2 | 3 | 5 |
| *Ability to Shock* | | | | | |
| Transportability | 3 | 3 | 3 | 0 | 2 |
| Mobility | 8 | 7 | 4 | 1 | 3 |
| Firepower | 9 | 8 | 4 | 3 | 3 |
| Protection | 5 | 3 | 2 | 1 | 0 |
| Stealth | 7 | 5 | 4 | 1 | 0 |
| Self-sufficiency | 0 | 0 | 0 | 1 | 2 |
| *Survivability* | | | | | |
| Transportability | 1 | 1 | 1 | 0 | 0 |
| Mobility | 7 | 5 | 5 | 0 | 0 |
| Firepower | 7 | 7 | 3 | 4 | 1 |
| Protection | 8 | 7 | 4 | 1 | 1 |
| Stealth | 8 | 7 | 2 | 1 | 0 |
| Self-sufficiency | 2 | 2 | 2 | 3 | 3 |
| *Sustainability* | | | | | |
| Transportability | 0 | 0 | 0 | 0 | 3 |
| Mobility | 1 | 0 | 1 | 0 | 1 |
| Firepower | 0 | 0 | 0 | 3 | 1 |
| Protection | 0 | 0 | 0 | 1 | 2 |
| Stealth | 0 | 0 | 0 | 1 | 0 |
| Self-sufficiency | 4 | 2 | 1 | 7 | 9 |

NOTE: Shading indicates that experts' responses spanned 7 or more levels on the 0-to-9 scale, while the ratings with a response range of 3 or less are shown in **bold**.

## Table 6.6

## Degree of Overall Characteristic Contributions to Force Attributes

| Characteristic | Proportion of Contribution to Attribute | | | | | |
|---|---|---|---|---|---|---|
| | Deploy-ability | Lethality | Maneuver-ability | Ability to Shock | Surviv-ability | Sustain-ability |
| *System* | | | | | | |
| Transportability | 0.2262 | 0.0000 | 0.0287 | 0.0368 | 0.0033 | 0.0731 |
| Mobility | 0.0238 | 0.1007 | 0.1626 | 0.1105 | 0.0856 | 0.0731 |
| Firepower | 0.0060 | 0.1493 | 0.0656 | 0.1271 | 0.0911 | 0.0068 |
| Protection | 0.0000 | 0.0752 | 0.0820 | 0.0724 | 0.1233 | 0.0221 |
| Stealth | 0.0000 | 0.0765 | 0.0724 | 0.0914 | 0.1089 | 0.0187 |
| Self-sufficiency | 0.1230 | 0.0498 | 0.0765 | 0.0392 | 0.0578 | 0.1922 |
| *Operational* | | | | | | |
| Awareness | 0.0337 | 0.1468 | 0.1503 | 0.1378 | 0.1433 | 0.0697 |
| Coordination | 0.1429 | 0.1299 | 0.1120 | 0.1306 | 0.1256 | 0.0646 |
| Adaptability | 0.0952 | 0.1104 | 0.1066 | 0.0914 | 0.0989 | 0.1054 |
| Economy | 0.1429 | 0.0898 | 0.0601 | 0.0938 | 0.1033 | 0.1633 |
| Ability to Support | 0.2063 | 0.0716 | 0.0833 | 0.0689 | 0.0589 | 0.2109 |

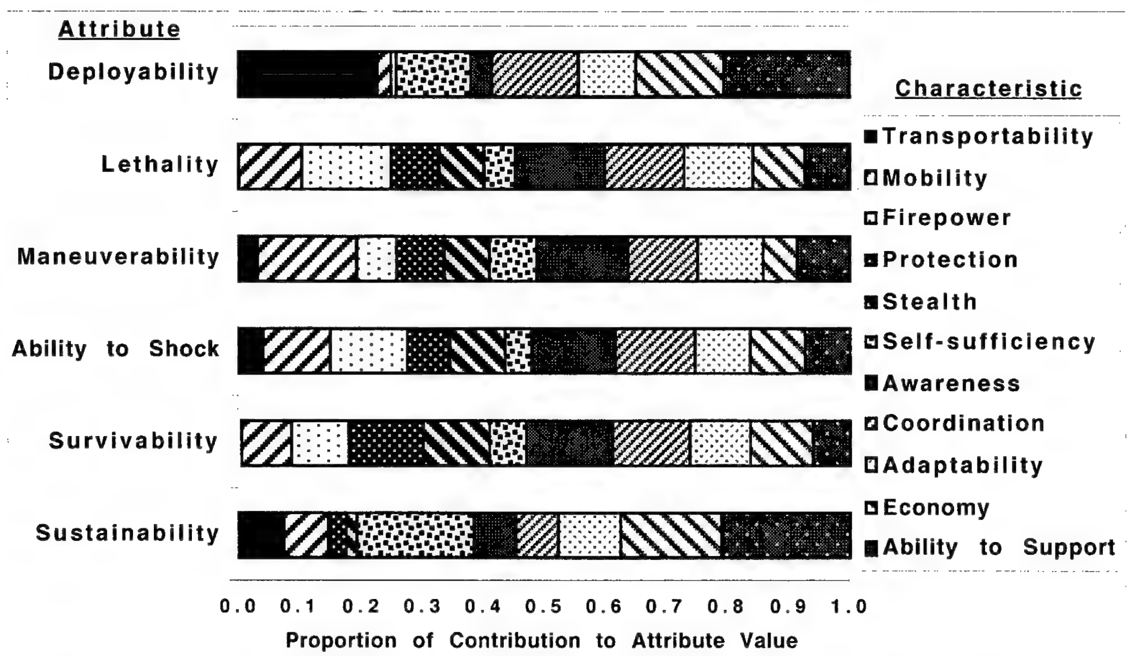



**Figure 6.2. Distribution of Characteristic Contributions to the Level of Each Force Attribute**

These weights, which represent the proportion of each characteristic's contribution to every attribute, have a number of interesting features as a group. In general, the contributions to an attribute tend to be spread out over many

characteristics rather than being concentrated in just a few. For example, mobility and awareness make the largest contributions to maneuverability, but together account for less than one third of all contributions, with the remaining nine characteristics each accounting for at least a few percent. However, the contributions of some system characteristics to certain attributes are negligible. Transportability makes essentially no contribution to lethality or survivability, while deployability and sustainability receive only minimal contributions from firepower, and neither protection nor stealth make any contribution whatsoever to deployability. By contrast, each operational characteristic contributes at least a few percent of the total for every attribute. The following discussion compares these weights for two sets of attributes: deployability and sustainability, which relate to power projection; and lethality, maneuverability, ability to shock, and survivability, which all relate to battlefield dominance.[66]

The largest contributors to deployability are transportability and ability to support, both with weights of over 0.20, indicating that a force must be light and well-supported to be deployed quickly and easily. Sustainability also relies on these two characteristics, as well as economy and self-sufficiency, much more than the other four attributes, but differs from deployability by placing more emphasis on self-sufficiency and less on transportability. Both attributes involve transporting people, equipment and supplies over long distances, often with limited support from pre-existing infrastructures. The timing associated with each attribute, however, requires a different focus: during deployment, what matters is getting there quickly, but once it has been deployed, a force that is efficient and independent is easier to sustain. Both transportability and sustainability receive over 60 percent of their contributions from operational characteristics. But, for each of the other four attributes, these contributions only

---

[66] This division is used by U. S. Army Armor Center (1999), which uses the same attributes, except that it does not include ability to shock, and does include an additional attribute, MANPRINT, which encompasses training and retention factors.

amount to just over 50 percent. Thus, force projection relies on operational capabilities a bit more than on system technologies, relative to dominance.

The contributions to the battlefield dominance attributes—lethality, ability to shock, survivability and maneuverability—all come from a similarly balanced mix of characteristics. Every characteristic, except transportability, contributes to lethality, with over 40 percent of the total coming from three characteristics: firepower, awareness and coordination. This combination implies that knowing where potential targets are, and being able to make timely high-quality decisions, are just as important as raw firepower in determining overall lethality. Ability to shock receives large contributions from awareness and coordination as well, but relies on both mobility and firepower about equally. It also differs from lethality by requiring some transportability, and placing a bit more emphasis on stealth and a little less on self-sufficiency, since its focus is on the element of surprise. Survivability is also similar to lethality, but relies less on firepower, and more on protection and stealth, since they improve the chances of survival more directly. Mobility and awareness are the most important characteristics for maneuverability, which also requires some transportability, since a force must know its surroundings and be able to move in order to maneuver effectively.

## 6.4 IMPORTANCE OF SYSTEM CHARACTERISTICS IN SYSTEM ROLES

The experts assessed the importance of all the system characteristics for each of the nine system roles. The analysis uses their median responses[67] as the system role importance ratings (SRI[j,g]) that are shown in Table 6.7. These ratings are used to adjust the quantity-based weights associated with each system to account for its design and function when the force-level system characteristics are calculated. This approach aggregates characteristics in a

--------

[67] As with the characteristic contribution ratings, if there is an even number of responses, the lower of the two middle ratings is used, rather than their mean, to ensure an integer rating.

manner that allows systems to complement one another by playing roles that focus on their strengths and downplay their weaknesses.

**Table 6.7**

**Importance of System Characteristics in Roles that Systems Can Play in a Force**

| System Role | Rating of System Characteristic's Importance for Role | | | | | |
|---|---|---|---|---|---|---|
| | Transportability | Mobility | Firepower | Protection | Stealth | Self-sufficiency |
| Direct Fire Attack | 2 | 7 | **9** | **9** | 4 | 5 |
| Direct Fire Support | 3 | 6 | **9** | **8** | 5 | 5 |
| Indirect Fire Close | 4 | 5 | **9** | **5** | 5 | 4 |
| Indirect Fire Far | 3 | 3 | **8** | **4** | 3 | 3 |
| Close Air Support | 7 | 7 | 7 | 4 | 5 | 3 |
| Deep Air Interdiction | 7 | 8 | 7 | 3 | 6 | 3 |
| Reconnaissance Scout | 8 | **8** | 2 | 3 | 8 | 6 |
| Reconnaissance Strike | 7 | **8** | 5 | 4 | 7 | 6 |
| Special Operations | 9 | **9** | 5 | **3** | 9 | 9 |

NOTE: Shading indicates that experts' responses spanned 7 or more levels on the 0-to-9 scale, while the ratings with a response range of 3 or less are shown in **bold**.

There are a couple of clear patterns in the amount of agreement among the experts for these ratings, as indicated in Table 6.7, where the cells of ratings with a large response range are shaded, and those with a small range are in **bold**. First, in all of the air and reconnaissance roles (5, 6, 7 and 8), the range of responses is large for transportability and self-sufficiency. In the deep air interdiction role, the response range is high for the stealth rating, and it is high for firepower in the reconnaissance strike role. The experts disagreed greatly on the self-sufficiency ratings in the two direct fire roles. The response ranges for the transportability and stealth ratings were moderately high in these two roles. Only one rating in either of the two indirect fire roles had a large response range:

transportability in the indirect fire far role. There was an unusually high level of agreement among the experts for some ratings. In particular, their responses differed very little on the ratings of firepower and protection in all of the direct and indirect fire roles. And, they agreed quite strongly on the ratings for mobility in the two reconnaissance roles, and for both mobility and protection in the special operations role.

There are also some interesting patterns in the values of these ratings. Very low ratings are quite rare (no 0s or 1s, and only a couple of 2s), while very high ratings are quite common (15 are either 8 or 9). This does not appear to be a problem, however, since the ratings span several scale levels across both characteristics and roles. Other patterns are evident in the ratings for two subsets of the system roles: the direct and indirect fire roles (1, 2, 3 and 4); and the air, reconnaissance and special operations roles (5, 6, 7, 8 and 9).

The ratings for the two direct fire roles, attack and support, are very similar, ranging from 8 or 9 for firepower and protection, down to 2 or 3 for transportability. These ratings emphasize the potency and defenses of typical direct fire systems like tanks, and place less emphasis on their size and weight. Firepower is also rated just as highly in the two indirect fire roles, close and far, while all of the other system characteristics, including protection, receive moderate to strong ratings of only 3 to 5. These systems may, for example, use less armor to reduce weight, and increase speed and efficiency.

The two air roles, close air support and deep air interdiction, also have ratings that are similar to one another. Three characteristics—transportability, mobility and firepower—have fairly strong ratings of 7 or 8, while protection and self-sufficiency have moderate ratings of 3 or 4, with the stealth ratings falling in between at 5 or 6. This emphasis mirrors the strengths and weaknesses of modern ground-attack aircraft and missiles, so their inclusion in a force will tend to complement ground-based systems.

The ratings for the two reconnaissance roles, scout and stealth, are somewhat similar to those of the air roles, but with two important differences. First, stealth and self-sufficiency are rated a couple of notches higher, since reconnaissance systems operating on or near the ground need to be less conspicuous and more independent than aircraft at high altitudes. Second, firepower has a low rating of 2 in the scout role, and a strong rating of 5 in the strike role, reflecting the principal distinction between these two types of reconnaissance systems.

The special operations role is unique; it gives four characteristics—stealth, mobility, transportability, and self-sufficiency—the highest possible rating of 9, while the two remaining characteristics, firepower and protection, are given strong and moderate ratings of 5 and 3, respectively. These ratings match fairly well with the characteristics of such systems, except that the tradeoff between stealth and mobility is usually decided in favor of stealth, since these systems need to avoid detection because they usually lack protection and firepower.

## 6.5 CONCLUDING REMARKS

This chapter described the results of phase one of the HIMAX process—preparation. These results included the value function assignments for the characteristics, the attribute and characteristic weights, and the system role importance ratings. All of these inputs are used in phase three to evaluate options using the HIMAX decision model; these evaluation results are described in Chapter 8. Chapter 7 presents the aggregated, force-level characteristics for all of the options under consideration, as calculated in phase two—generation.

# 7. GENERATION

The second phase of the HIMAX process—generation—defines and characterizes the force options being evaluated in the analysis. These options were described in Chapter 5, so this chapter focuses on presenting the force-level characteristics of each option, and discussing how they are derived from its composition and the specifications of its components. The importance weights associated with all the force components are presented first for each near-term and far-term option. These weights indicate how much a component contributes to the force-level characteristics of an option. The force-level characteristic values for each option, which are presented next, are calculated from the characteristics of its components using the corresponding importance weights. These option characteristics are used to determine its attributes in phase three.

## 7.1 IMPORTANCE OF FORCE COMPONENT CHARACTERISTICS

The model assigns weights to the system and operational force components to indicate how important they are in determining the overall characteristics of a force option. The importance weights for the five operational concepts (cw[t,f]) are estimated directly for each option.[68] The system importance weights combine the subjective role ratings (see above) with the composition of each option. As described in Chapter 3, the ratings of the role assigned to each system (p[j,s]) are multiplied by the quantity weights (q[s,f])—the number of each system type as a fraction of the force—and re-normalized to obtain the system importance weights (bw[j,s,f]). Table 7.1 shows the quantity weights for all the systems in each near-term force option, along with the corresponding importance weights for each characteristic. Table 7.2 does the same for each far-term force option.

--------

[68] Tables 5.5 and 5.9 show the operational weights for the near-term and far-term options, respectively.

## Table 7.1

## Importance of Near-Term Systems in Determining Force-Level Characteristics

| *Option* / System | Fraction of Force | Fraction of Weight on System in Force-Level Characteristic Calculation: Transport-ability | Mobility | Firepower | Protection | Stealth | Self-sufficiency |
|---|---|---|---|---|---|---|---|
| *Heavy* | | | | | | | |
| M1A2 | 0.2333 | 0.1049 | 0.2459 | 0.2551 | 0.3457 | 0.1889 | 0.2857 |
| M2(3)A3 | 0.1833 | 0.1236 | 0.1656 | 0.2004 | 0.2414 | 0.1855 | 0.2245 |
| M2A3-FGM | 0.0333 | 0.0300 | 0.0251 | 0.0364 | 0.0274 | 0.0337 | 0.0327 |
| M109A6 | 0.0667 | 0.0599 | 0.0502 | 0.0729 | 0.0549 | 0.0675 | 0.0653 |
| MLRS | 0.0500 | 0.0449 | 0.0376 | 0.0547 | 0.0412 | 0.0506 | 0.0490 |
| Javelin | 0.0500 | 0.0337 | 0.0452 | 0.0547 | 0.0658 | 0.0506 | 0.0612 |
| AH-64D | 0.1000 | 0.1573 | 0.1054 | 0.0850 | 0.0658 | 0.1012 | 0.0735 |
| A-10 | 0.1083 | 0.1704 | 0.1142 | 0.0921 | 0.0713 | 0.1096 | 0.0796 |
| TAC-AIR | 0.1000 | 0.1573 | 0.1205 | 0.0850 | 0.0494 | 0.1214 | 0.0735 |
| NTACMS | 0.0750 | 0.1180 | 0.0903 | 0.0638 | 0.0370 | 0.0911 | 0.0551 |
| *Medium* | | | | | | | |
| LAV-DFV | 0.1217 | 0.0523 | 0.1314 | 0.1382 | 0.1898 | 0.0948 | 0.1461 |
| LAV-IFV | 0.1304 | 0.0841 | 0.1206 | 0.1480 | 0.1807 | 0.1269 | 0.1566 |
| LAV-APC | 0.1217 | 0.0785 | 0.1126 | 0.1382 | 0.1687 | 0.1184 | 0.1461 |
| LAV-MOR | 0.0348 | 0.0299 | 0.0268 | 0.0395 | 0.0301 | 0.0338 | 0.0334 |
| LAV-HOW | 0.0522 | 0.0449 | 0.0402 | 0.0592 | 0.0452 | 0.0508 | 0.0501 |
| LAV-FGM | 0.0696 | 0.0598 | 0.0536 | 0.0789 | 0.0602 | 0.0677 | 0.0668 |
| LAV-REC | 0.0522 | 0.0897 | 0.0643 | 0.0132 | 0.0271 | 0.0812 | 0.0752 |
| HIMARS | 0.0261 | 0.0168 | 0.0121 | 0.0263 | 0.0181 | 0.0152 | 0.0188 |
| Javelin | 0.0522 | 0.0336 | 0.0483 | 0.0592 | 0.0723 | 0.0508 | 0.0626 |
| AH-64D | 0.0696 | 0.1047 | 0.0751 | 0.0614 | 0.0482 | 0.0677 | 0.0501 |
| A-10 | 0.1130 | 0.1701 | 0.1220 | 0.0998 | 0.0783 | 0.1100 | 0.0814 |
| TAC-AIR | 0.1043 | 0.1570 | 0.1287 | 0.0921 | 0.0542 | 0.1218 | 0.0752 |
| NTACMS | 0.0522 | 0.0785 | 0.0643 | 0.0461 | 0.0271 | 0.0609 | 0.0376 |
| *Light* | | | | | | | |
| HMV-TOW | 0.2124 | 0.1406 | 0.2054 | 0.2286 | 0.2922 | 0.2065 | 0.2586 |
| Javelin | 0.2124 | 0.1406 | 0.2054 | 0.2286 | 0.2922 | 0.2065 | 0.2586 |
| Mortar | 0.0796 | 0.0703 | 0.0642 | 0.0857 | 0.0685 | 0.0775 | 0.0776 |
| HMV-HOW | 0.0708 | 0.0625 | 0.0571 | 0.0762 | 0.0609 | 0.0688 | 0.0690 |
| HMV-FGM | 0.1062 | 0.0938 | 0.0856 | 0.1143 | 0.0913 | 0.1033 | 0.1034 |
| AH-64D | 0.0708 | 0.1094 | 0.0799 | 0.0593 | 0.0487 | 0.0688 | 0.0517 |
| A-10 | 0.1062 | 0.1641 | 0.1198 | 0.0889 | 0.0731 | 0.1033 | 0.0776 |
| TAC-AIR | 0.0885 | 0.1367 | 0.1141 | 0.0741 | 0.0457 | 0.1033 | 0.0647 |
| NTACMS | 0.0531 | 0.0820 | 0.0685 | 0.0444 | 0.0274 | 0.0620 | 0.0388 |
| *Air Only* | | | | | | | |
| TAC-AIR | 0.8000 | 0.8000 | 0.8000 | 0.8000 | 0.8000 | 0.8000 | 0.8000 |
| NTACMS | 0.2000 | 0.2000 | 0.2000 | 0.2000 | 0.2000 | 0.2000 | 0.2000 |
| *Air + SOF* | | | | | | | |
| AH-64D | 0.1404 | 0.1305 | 0.1244 | 0.1518 | 0.1667 | 0.1093 | 0.0920 |
| A-10 | 0.2281 | 0.2121 | 0.2022 | 0.2466 | 0.2708 | 0.1776 | 0.1494 |
| TAC-AIR | 0.2105 | 0.1958 | 0.2133 | 0.2276 | 0.1875 | 0.1967 | 0.1379 |
| NTACMS | 0.1579 | 0.1469 | 0.1600 | 0.1707 | 0.1406 | 0.1475 | 0.1034 |
| SOF-RST | 0.2632 | 0.3147 | 0.3000 | 0.2033 | 0.2344 | 0.3689 | 0.5172 |

These system importance weights indicate how much emphasis is placed on each component system, based on its role and numbers in the force, when aggregate characteristics are being calculated. If the importance weight for a particular characteristic is much higher (or lower) than the corresponding quantity weight, then that characteristic is more (or less) important for this system than it is for most of the other systems in the force. Several patterns in the importance weights for the various component systems are highlighted here.

The most apparent pattern involves the direct-fire and air systems in the force options that provide a considerable ground presence. In these ground-based options—heavy, medium and light in the near term, and lean heavy, future medium, and enhanced light in the far term—the importance weights for transportability and protection deviate substantially from the corresponding quantity weights for each of the direct-fire and air systems. Protection is much more important than transportability for the direct-fire systems, which play one of the two direct-fire roles, attack or support. Exactly the opposite is true for the systems that play one of the two air roles, close air support or deep air interdiction roles. Direct-fire systems comprise about a third to two fifths of the systems in these options, but together receive over half the weight for protection, while their contribution to transportability is much smaller. Air systems are equally dominant in their contributions to transportability, but have relatively low importance weights for protection. The near-term heavy force provides a clear example of these stark differences: the two main direct-fire systems, the M1A2 and the M2A3/M3A3, comprise over 40 percent of the systems, but account for just under 60 percent of the weight for protection, and only about 13 percent of the weight for transportability; the air systems, the AH-64D, A-10, TAC-AIR and NTACMS, which comprise less than 40 percent of all systems, receive 60 percent of the transportability weight, and only about 22 percent of the protection weight. This complementary arrangement takes advantage of the strengths of these types of systems and downplays their weaknesses. In

particular, it reflects how air and ground systems can work in concert. The aircraft and missiles provide an early presence, degrade enemy forces, and cover the arrival of heavier direct-fire systems that have the protection needed for dangerous ground situations.

The air systems also receive relatively low importance weights for self-sufficiency in all of the non-air-only options. Aircraft, including helicopters and missiles, are not very self-sufficient, since they consume fuel, parts, maintenance and other support quite voraciously. But, this characteristic is not that vital for them because they are co-located with their support infrastructure, well away from the battlefield. This emphasis is especially pronounced in the near-term air + SOF option. Air systems (AH-64D, A-10, TAC-AIR and NTACMS) comprise almost three quarters of this force, but account for less than half of the weight on self-sufficiency. SOF-RST teams, the only other type of system in this option, are highly independent and their role emphasizes self-sufficiency much more than the air roles do, so they receive an importance weight of 0.52, which is exactly twice their quantity weight.

There is one air-based system in the far term that does not play one of the two air roles, the Comanche RAH-66 helicopter, which plays a reconnaissance strike role instead. In this role, self-sufficiency and stealth are more important than in the air roles, and firepower is emphasized less, since a system in this role must loiter and avoid detection while collecting information and targeting enemy systems. Thus, it is not surprising that this system has an interesting mix of importance weights for the far-term options. In the ground-based options (lean heavy, future medium and enhanced light), the RAH-66 receives relatively low weights for firepower and protection, and fairly high weights for the remaining characteristics, especially transportability and self-sufficiency. For example, the RAH-66 comprises about 4.6 percent of the systems in the future medium option, but its importance weights range from about 0.03 for firepower and protection to over 0.06 for transportability, self-sufficiency and stealth. In

the air-based options (advanced air only and advanced air + SOF), self-sufficiency is the only characteristic that receives disproportionately high importance weights, and firepower is the only one with relatively low weights. Indeed, in the advanced air only option, where RAH-66s are one sixth of the force, self-sufficiency has an importance weight of almost 0.29, while it weight for firepower is only 0.125.

Systems that play a reconnaissance scout role have an even wider range of importance weights. These systems include: LAV-REC in the medium option (the only near-term scout system), FSCS in the lean heavy option, FCS-REC in the future medium option, and RST-V in the enhanced light option. All these scout vehicles have a similar pattern of importance weights: extremely high for transportability; fairly high for stealth, self-sufficiency and (sometimes) mobility; quite low for protection; and extremely low for firepower. For example, FCS-REC vehicles comprise about 5 percent of future medium, and its importance weights range from just 0.013 for firepower all the way up to 0.086 for transportability.

One other class of ground vehicles exhibits an unusual pattern in these weights. Systems that play an indirect fire far role (e.g., mobile long-range rocket artillery vehicles) received relatively low weights for every characteristic except firepower. The reason for this is that the ratings for this role follow the same pattern: very high (8) for firepower, but moderate (3 or 4) for all of the other characteristics.[69] These ratings are low relative to most of the other roles, so these systems will tend to receive lower importance weights than systems that play other roles. The HIMARS system, in the near-term medium option, is a case in point: its importance weight for firepower is only slightly higher than its quantity weight, about 0.026, while all of the other characteristic importance weights are much lower, with the mobility having the lowest, at only 0.012.

--------

[69] The system role ratings used in the analysis are shown in Table 6.7.

## Table 7.2

## Importance of Far-Term Systems in Determining Force-Level Characteristics

| *Option* System | Fraction of Force | Fraction of Weight on System in Force-Level Characteristic Calculation: Transport-ability | Mobility | Firepower | Protection | Stealth | Self-sufficiency |
|---|---|---|---|---|---|---|---|
| *Lean Heavy* | | | | | | | |
| M1A3 | 0.1619 | 0.0643 | 0.1647 | 0.1886 | 0.2799 | 0.1217 | 0.2024 |
| M2A4 | 0.1619 | 0.0964 | 0.1412 | 0.1886 | 0.2488 | 0.1521 | 0.2024 |
| M2A4-FGM | 0.0486 | 0.0386 | 0.0353 | 0.0566 | 0.0467 | 0.0456 | 0.0486 |
| Crusader | 0.0972 | 0.0771 | 0.0706 | 0.1131 | 0.0933 | 0.0913 | 0.0972 |
| MLRS | 0.0243 | 0.0145 | 0.0106 | 0.0251 | 0.0187 | 0.0137 | 0.0182 |
| FSCS | 0.0324 | 0.0514 | 0.0376 | 0.0084 | 0.0187 | 0.0487 | 0.0486 |
| AH-64D+ | 0.0729 | 0.1012 | 0.0741 | 0.0660 | 0.0560 | 0.0684 | 0.0547 |
| RAH-66 | 0.0364 | 0.0506 | 0.0424 | 0.0236 | 0.0280 | 0.0479 | 0.0547 |
| A-TAC-AIR | 0.2915 | 0.4048 | 0.3388 | 0.2640 | 0.1680 | 0.3285 | 0.2186 |
| A-NTACMS | 0.0729 | 0.1012 | 0.0847 | 0.0660 | 0.0420 | 0.0821 | 0.0547 |
| *Future Medium* | | | | | | | |
| FCS-DFV | 0.1421 | 0.0600 | 0.1480 | 0.1648 | 0.2246 | 0.1076 | 0.1667 |
| FCS-IFV | 0.1523 | 0.0965 | 0.1360 | 0.1766 | 0.2139 | 0.1441 | 0.1786 |
| FCS-APC | 0.1421 | 0.0900 | 0.1269 | 0.1648 | 0.1996 | 0.1345 | 0.1667 |
| FCS-ART | 0.0406 | 0.0343 | 0.0302 | 0.0471 | 0.0357 | 0.0384 | 0.0381 |
| FCS-REC | 0.0508 | 0.0857 | 0.0604 | 0.0131 | 0.0267 | 0.0768 | 0.0714 |
| ARES | 0.0609 | 0.0514 | 0.0453 | 0.0706 | 0.0535 | 0.0576 | 0.0571 |
| A-MLRS | 0.0305 | 0.0193 | 0.0136 | 0.0314 | 0.0214 | 0.0173 | 0.0214 |
| AH-64D+ | 0.0914 | 0.1350 | 0.0952 | 0.0824 | 0.0642 | 0.0865 | 0.0643 |
| RAH-66 | 0.0457 | 0.0675 | 0.0544 | 0.0294 | 0.0321 | 0.0605 | 0.0643 |
| A-TAC-AIR | 0.1827 | 0.2701 | 0.2175 | 0.1648 | 0.0963 | 0.2075 | 0.1286 |
| A-NTACMS | 0.0609 | 0.0900 | 0.0725 | 0.0549 | 0.0321 | 0.0692 | 0.0429 |
| *Enhanced Light* | | | | | | | |
| AHMV-FOT | 0.1547 | 0.1065 | 0.1570 | 0.1759 | 0.2231 | 0.1472 | 0.1759 |
| AHMV-APC | 0.0773 | 0.0532 | 0.0785 | 0.0879 | 0.1116 | 0.0736 | 0.0879 |
| RST-V | 0.0773 | 0.1420 | 0.1047 | 0.0195 | 0.0418 | 0.1178 | 0.1055 |
| A-Javelin | 0.1326 | 0.0913 | 0.1346 | 0.1507 | 0.1912 | 0.1262 | 0.1508 |
| A-Mortar | 0.0884 | 0.0811 | 0.0748 | 0.1005 | 0.0797 | 0.0841 | 0.0804 |
| Small AFSS | 0.1989 | 0.1825 | 0.1682 | 0.2261 | 0.1793 | 0.1893 | 0.1809 |
| Large AFSS | 0.0994 | 0.0684 | 0.0505 | 0.1005 | 0.0717 | 0.0568 | 0.0678 |
| RAH-66 | 0.0497 | 0.0798 | 0.0673 | 0.0314 | 0.0359 | 0.0662 | 0.0678 |
| A-TAC-AIR | 0.0884 | 0.1420 | 0.1196 | 0.0782 | 0.0478 | 0.1009 | 0.0603 |
| A-NTACMS | 0.0331 | 0.0532 | 0.0449 | 0.0293 | 0.0179 | 0.0379 | 0.0226 |
| *Advanced Air Only* | | | | | | | |
| RAH-66 | 0.1667 | 0.1667 | 0.1667 | 0.1250 | 0.2105 | 0.1892 | 0.2857 |
| A-TAC-AIR | 0.6667 | 0.6667 | 0.6667 | 0.7000 | 0.6316 | 0.6486 | 0.5714 |
| A-NTACMS | 0.1667 | 0.1667 | 0.1667 | 0.1750 | 0.1579 | 0.1622 | 0.1429 |

| *Option* System | Fraction of Force | Fraction of Weight on System in Force-Level Characteristic Calculation Transport-ability | Mobility | Firepower | Protection | Stealth | Self-sufficiency |
|---|---|---|---|---|---|---|---|
| *Advanced Air + SOF* | | | | | | | |
| Small AFSS | 0.1706 | 0.1046 | 0.1190 | 0.2206 | 0.2400 | 0.1399 | 0.1538 |
| Large AFSS | 0.0853 | 0.0392 | 0.0357 | 0.0980 | 0.0960 | 0.0420 | 0.0577 |
| AH-64D+ | 0.0853 | 0.0915 | 0.0833 | 0.0858 | 0.0960 | 0.0699 | 0.0577 |
| RAH-66 | 0.0427 | 0.0458 | 0.0476 | 0.0306 | 0.0480 | 0.0490 | 0.0577 |
| A-TAC-AIR | 0.3412 | 0.3660 | 0.3810 | 0.3431 | 0.2880 | 0.3357 | 0.2308 |
| A-NTACMS | 0.0853 | 0.0915 | 0.0952 | 0.0858 | 0.0720 | 0.0839 | 0.0577 |
| SOF-RST | 0.0948 | 0.1307 | 0.1190 | 0.0681 | 0.0800 | 0.1399 | 0.1923 |
| SOF-AST | 0.0948 | 0.1307 | 0.1190 | 0.0681 | 0.0800 | 0.1399 | 0.1923 |

## 7.2 AGGREGATE CHARACTERISTICS OF FORCE OPTIONS

The characteristic values of force components are aggregated to determine the overall force-level characteristics of each option. The characteristic values of a system or operational component are calculated by applying the assigned value functions to its characteristic ratings. Since these ratings are actually discrete distributions involving three consecutive integer levels, the resulting system and operational characteristic values (bv[j,s] and cv[k,t], respectively) are also three-point distributions, but on a continuous scale. These distributions represent technological and environmental uncertainty in the performance of each system type and operational concept.

The aggregate force-level system and operational characteristic values for each option (B[j,f] and C[k,t], respectively) are calculated from the corresponding component values (bv[j,s] and cv[k,t]) and importance weights (bw[j,s,f] and cw[t,f]), as described in Chapter 3. The median values of these force-level characteristics are shown for the near-term options in Table 7.3, and for the far-term options in Table 7.4. Figure 7.1 shows a column chart of the system characteristic values for the five near-term options, and Figure 7.2 shows their operational characteristics. Figures 7.3 and 7.4 show the system and operational characteristics, respectively, of the five far-term options. The error bars in these

four column charts represent 90-percent confidence intervals, extending from the 5th to the 95th percentile of each characteristic value distribution.

**Table 7.3**

**Median Force-Level Characteristics of Near Term Force Options**

| Characteristic | Force Option | | | | |
|---|---|---|---|---|---|
| | Heavy | Medium | Light | Air Only | Air + SOF |
| *System* | | | | | |
| Transportability | 5.56 | 6.68 | 8.43 | 8.94 | 8.64 |
| Mobility | 6.21 | 6.56 | 4.27 | 7.83 | 4.16 |
| Firepower | 6.16 | 5.13 | 5.82 | 6.57 | 4.43 |
| Protection | 3.54 | 2.28 | 1.45 | 2.07 | 1.92 |
| Stealth | 2.33 | 2.68 | 3.82 | 6.07 | 5.86 |
| Self-sufficiency | 2.83 | 3.84 | 4.65 | 1.48 | 3.98 |
| *Operational* | | | | | |
| Awareness | 7.03 | 6.63 | 5.80 | 3.47 | 6.53 |
| Coordination | 5.89 | 5.54 | 3.92 | 5.00 | 5.00 |
| Adaptability | 4.62 | 4.75 | 3.30 | 2.00 | 4.00 |
| Economy | 8.27 | 8.16 | 7.57 | 5.88 | 7.88 |
| Ability to Support | 5.39 | 5.49 | 5.81 | 6.00 | 5.00 |

**Table 7.4**

**Median Force-Level Characteristics of Far Term Force Options**

| Characteristic | Force Option | | | | |
|---|---|---|---|---|---|
| | Lean Heavy | Future Medium | Enhanced Light | Advanced Air Only | Advanced Air + SOF |
| *System* | | | | | |
| Transportability | 5.42 | 6.81 | 7.89 | 8.90 | 8.30 |
| Mobility | 7.22 | 7.90 | 3.30 | 8.36 | 3.85 |
| Firepower | 7.09 | 5.49 | 5.20 | 7.03 | 5.73 |
| Protection | 3.87 | 4.12 | 1.56 | 2.52 | 1.55 |
| Stealth | 2.98 | 3.79 | 5.32 | 6.05 | 6.38 |
| Self-sufficiency | 2.66 | 4.22 | 6.35 | 1.64 | 4.42 |
| *Operational* | | | | | |
| Awareness | 8.44 | 8.41 | 8.05 | 5.00 | 8.11 |
| Coordination | 7.90 | 8.12 | 7.59 | 7.83 | 8.77 |
| Adaptability | 6.59 | 6.47 | 6.02 | 4.00 | 5.79 |
| Economy | 8.74 | 8.74 | 8.57 | 7.00 | 8.62 |
| Ability to Support | 6.78 | 6.60 | 6.93 | 6.00 | 6.24 |

Many interesting observations can be drawn from these results for the near-term and far-term options. First, however, it is helpful to point out the impact that the assigned value functions have on the force-level characteristic

values. In both the near and far term, these assignments have a clear effect on the relative magnitudes of the different characteristics. Three of the system characteristics use non-linear value functions, with quite noticeable effects: mobility values are elevated substantially by the concave function; stealth values are suppressed by the convex value function; and transportability values are pushed up a bit when they are high, but pulled down a bit when they are low, by the s-shaped convex/cave function. Three operational characteristics also use non-linear value functions: coordination and awareness experience the more-when-high-and-less-when-low effect of the convex/cave function, while economy is elevated at all levels by the concave function.

The near-term options each have a somewhat different mix of characteristic values. The heavy and medium options are similar, especially in terms of their operational characteristics, but medium has more transportability and self-sufficiency, and substantially less firepower and protection. These differences reflect the lower weight and higher efficiency of the medium force, but also highlight that it is less potent and more vulnerable than the heavy force. The light force is quite different from these two options; it has much more transportability and stealth, plus a bit more self-sufficiency, but considerably less mobility and protection. These strengths and weaknesses are a result of this option's reliance on dismounted infantry teams and very lightly armored vehicles. The air only option is very strong on many characteristics, but also quite weak on many others; among all the options, it clearly has the highest levels of transportability, mobility, stealth, and even firepower, but also has the lowest levels of self-sufficiency, awareness, adaptability and economy. The air systems that comprise this option are the cause of these extremes; they are fast, elusive and potent, but not very efficient, and even though they have an effective support infrastructure, they still have many significant operational limitations. The air + SOF option is a bit more balanced than air only; it is has lot less mobility and firepower, due to its inclusion of SOF-RST teams on the ground, but

these teams make it much better in terms of self-sufficiency, awareness, adaptability and economy.

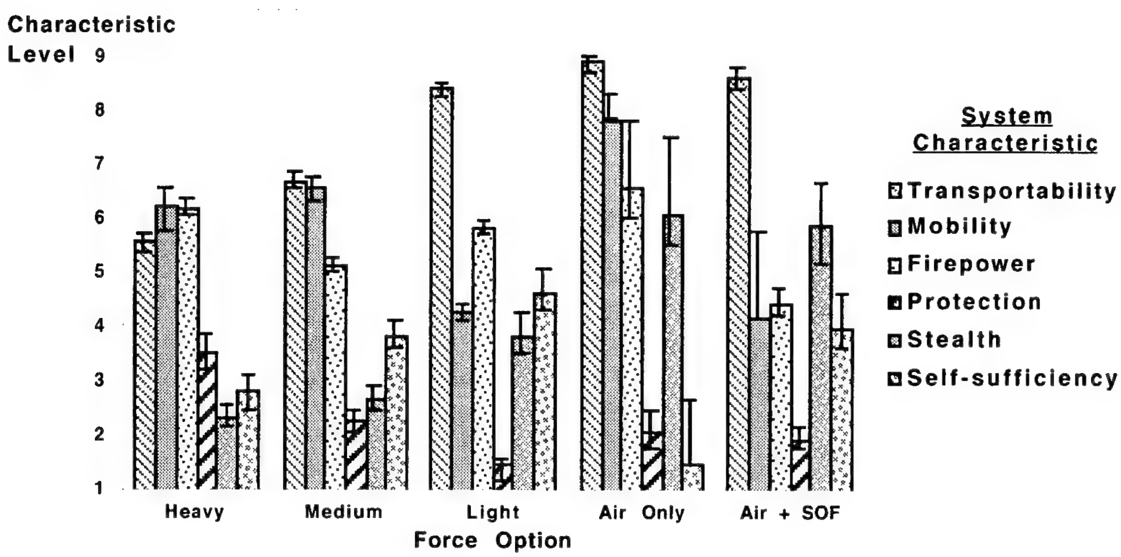



Figure 7.1. System Characteristic Values of Near-Term Force Options

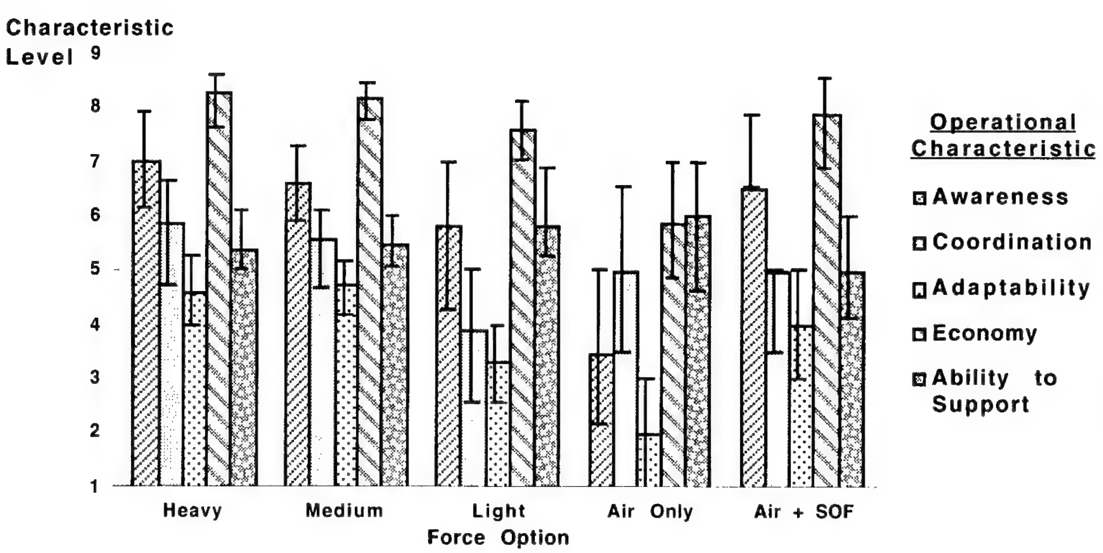



Figure 7.2. Operational Characteristic Values of Near-Term Force Options

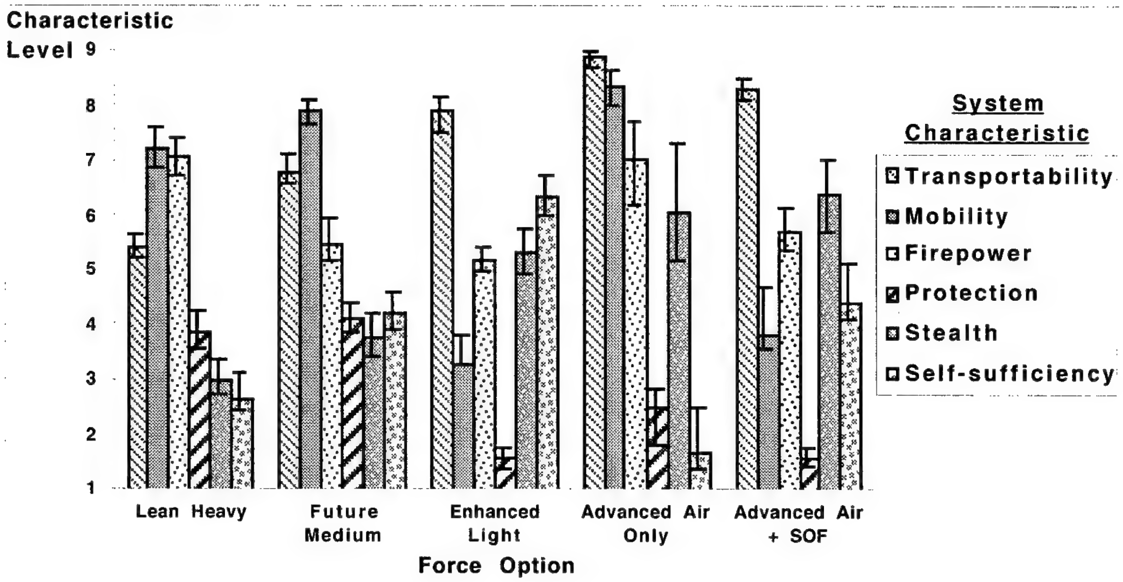



Figure 7.3. System Characteristic Values of Far-Term Force Options

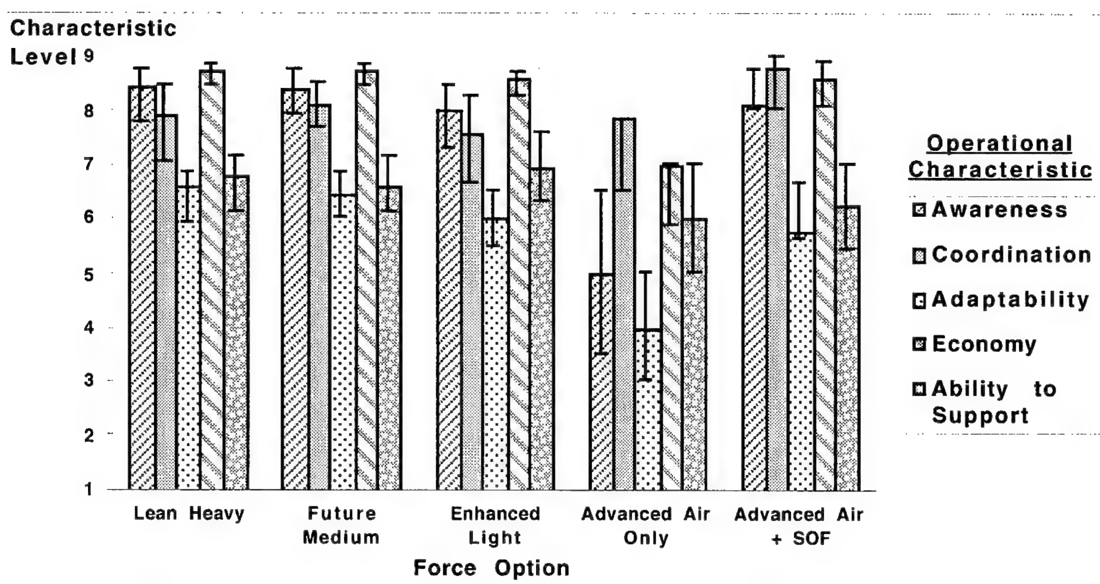



Figure 7.4. Operational Characteristic Values of Far-Term Force Options

## Generation

Many of the same observations are valid for the corresponding far-term options, although there are some important, yet subtle differences. The lean heavy option has moderately more mobility, firepower, protection and stealth than its near-term counterpart because of marginal technological improvements, and its operational characteristics are considerably better due to its utilization of advanced information technologies. The same is true of the future medium force, as compared to the near-term medium force, although its gains are even greater, especially in terms of protection and stealth, because it incorporates advanced, light-weight defensive systems and sensors. In fact, the future medium force surpasses or almost equals the lean heavy force on every characteristic except firepower. The enhanced light option is moderately better than the near-term light force on every characteristic except transportability, due to technological and operational advances. It is even stronger than the future medium force in terms of transportability, stealth and self sufficiency, but provides much less mobility and protection—it is still a vulnerable infantry force —and has similar or slightly lower operational characteristics. Compared to its near-term version, the advanced air only option is much better operationally because of organizational improvements and better sensors and communications gear, but its system characteristics are only slightly better. This option is more transportable and mobile than all the other far-term options, but is also the least self-sufficient, aware, adaptable and economic. The advanced air + SOF option has more firepower, stealth and self-sufficiency than its near-term counterpart, but is also a little less transportable and mobile. Its operational characteristics are all much better, and it has the highest coordination level of all the far-term options. These changes are the result of adding SOF-AST teams to its mix of systems, and the improved communication, sensor and information technologies that are implicit in the far-term operational concepts.

## 7.3 CONCLUDING REMARKS

This chapter described the results of the generation phase of the HIMAX process. In this phase, the characteristics of each option under consideration were determined by aggregating the characteristics of its components, using the corresponding importance weights. Chapter 8 describes the results of the evaluation phase, which include the attribute values of the options, and their effectiveness across a range of missions.

# 8. EVALUATION

The HIMAX evaluation model consist of two stages. The first stage determines the attributes of each option, based on its force-level characteristics and the corresponding contribution weights. The second stage calculates the effectiveness of all the options in every mission, weighting the force attributes somewhat differently in each case. This chapter presents the attributes of each near-term and far-term option, and discusses their mission effectiveness results. It then compares all of the options in each time frame to determine their rank frequencies (i.e., how often they place first, second, third, etc. in the Monte Carlo simulation runs). Selected option pairs—including the key pairs identified in Chapter 5—are also compared to obtain preference frequencies (i.e., how often one option is more effective than the other). Together, these results provide a baseline for the analysis; the excursions examined later in the exploration phase are always compared to this baseline.

## 8.1 ATTRIBUTES OF FORCE OPTIONS

The evaluation model determines the attribute levels of each option (A[i,f]) from its system and operational characteristics (B[j,f] and C[k,t], respectively) and their corresponding contributions weights (Y[i,j] and Z[i,k], respectively), as described in Chapter 3. Since the characteristics are actually distributions, not point values, the attributes calculated from them are also distributions. The median attribute values of the near-term options are shown in Table 8.1, and then depicted in Figure 8.1 with error bars indicating the 90-percent confidence interval for each distribution. The attributes of the far-term options are shown in Table 8.2, and depicted in Figure 8.2. Both figures show the same portion of the attribute value scale, from 3.0 to 7.5, so that the near-term and far-term results can be compared more easily. This narrower range of values also makes it easier to see the differences in attribute levels among all the options. The attribute

values span a smaller range than the underlying option characteristics because they are, in essence, just weighted averages of them, which allow the strengths of an option to compensate for its weaknesses.

**Table 8.1**

**Median Attribute Values for Near Term Force Options**

| Attribute | Force Option | | | | |
|---|---|---|---|---|---|
| | Heavy | Medium | Light | Air Only | Air + SOF |
| Deployability | 5.35 | 5.77 | 5.64 | 4.78 | 5.57 |
| Lethality | 5.23 | 5.02 | 4.42 | 4.37 | 4.73 |
| Maneuverability | 5.08 | 5.02 | 4.32 | 4.30 | 4.71 |
| Ability to Shock | 5.22 | 5.07 | 4.52 | 4.61 | 4.90 |
| Survivability | 4.95 | 4.73 | 4.13 | 4.11 | 4.63 |
| Sustainability | 5.06 | 5.41 | 5.15 | 4.01 | 5.08 |

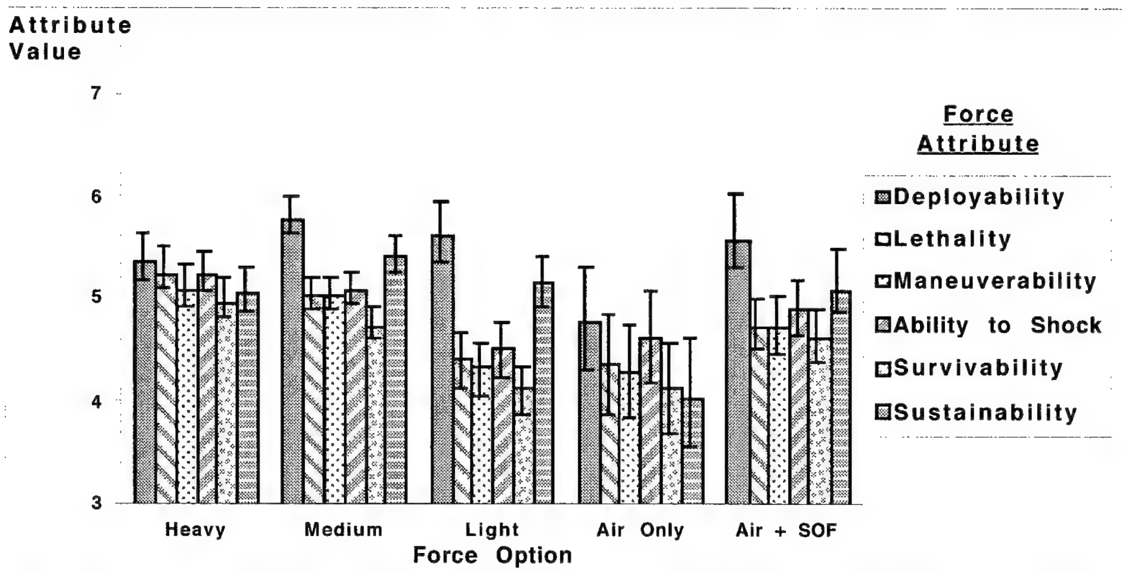



**Figure 8.1. Attribute Values for Near-Term Force Options**

There are clear patterns in the attribute levels of the options in each time frame, which provide some insight into their advantages and disadvantages relative to one another. The heavy option is the most balanced near-term force; all of its attribute values are at or slightly above 5, and have narrow confidence intervals. These values are the highest for the four dominance attributes: lethality, maneuverability, ability to shock and survivability. The medium force,

however, has the highest levels of deployability and sustainability, the two projection attributes, but is behind heavy on all of the other attributes. The light option is even more unbalanced; its projection attributes are a bit lower than those of the medium force, although the confidence intervals do overlap, and its dominance attributes are all substantially lower. The attribute levels of the air only option are all among the lowest for the near-term options. Specifically, this option is clearly less deployable and less sustainable than any of the other options, and has about the same levels of all the dominance attributes as the light option. Thus, the strengths of the air only option in some characteristics were not able to fully compensate for its many weaknesses. The air + SOF option, however, diversifies the air only option a bit and has substantially higher levels of every attribute as a result. In particular, this option now has almost the same levels of the two projection attributes as the light option, and its dominance attributes are all significantly higher.

**Table 8.2**

**Median Attribute Values for Far Term Force Options**

| | **Force Option** | | | | |
|---|---|---|---|---|---|
| **Attribute** | Lean Heavy | Future Medium | Enhanced Light | Advanced Air Only | Advanced Air + SOF |
| Deployability | 6.08 | 6.81 | 7.15 | 5.71 | 6.97 |
| Lethality | 6.30 | 6.44 | 5.58 | 5.37 | 5.82 |
| Maneuverability | 6.05 | 6.46 | 5.37 | 5.25 | 5.55 |
| Ability to Shock | 6.24 | 6.47 | 5.62 | 5.60 | 5.91 |
| Survivability | 5.92 | 6.23 | 5.30 | 5.06 | 5.52 |
| Sustainability | 5.76 | 6.49 | 6.47 | 4.80 | 6.13 |

The attributes of the far-term options are all higher than their near-term counterparts, often by more than a full point on the nine-point scale. These improvements are fairly uneven, however, so the relationships between the options are somewhat different. The lean heavy option is quite balanced, although its dominance attributes improved more relative to the near-term heavy option than its projection options did. The future medium option incorporates even larger improvements over its near-term counterpart; so large, in fact, that all

six of its attributes levels are higher than those of the lean heavy option, and the mix is equally balanced. The dominance attributes of the future medium option are higher than those of any other far-term option, but it is less deployable and only about as sustainable as the enhanced light option, which has the highest levels of these two projection attributes. The enhanced light option is much improved over the near-term light force, but its dominance attribute levels are still substantially lower than those of the lean heavy force. The advanced air only force, like its near-term option, has the lowest attribute levels among all of the options being considered, with its deficiencies still most pronounced for the two projection attributes, deployability and sustainability. The variation in these attribute levels due to technological and environmental uncertainties is, however, lower than in the near term. The advanced air + SOF option is clearly better than the advanced air only option on every attribute, although the confidence intervals for the dominance attributes do overlap a bit. The advanced air + SOF option also has lower projection attributes, but higher dominance attributes, than the enhanced light option—the same relationship as their near-term counterparts have.

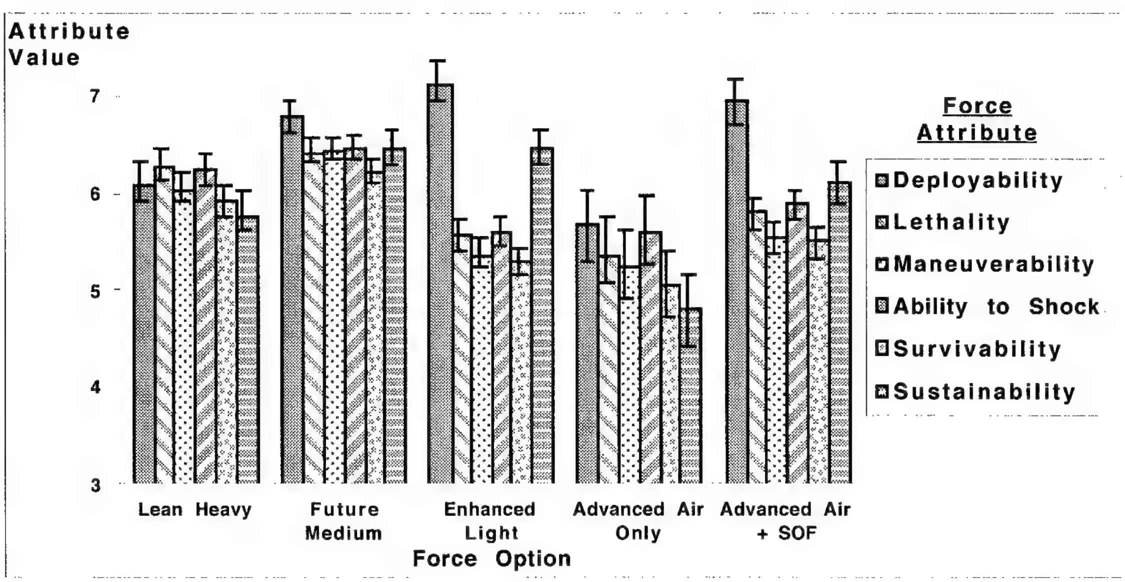



Figure 8.2. Attribute Values for Far-Term Force Options

## 8.2 MISSION EFFECTIVENESS

The effectiveness of an option in a particular mission is calculated from its attributes by weighting them according to their importance relative to one another for that mission. As Chapter 3 explains, the raw mission effectiveness values of each option are determined from its attributes (A[i,f]) and the corresponding attribute weights (X[i,m]). These same weights are applied to two other sets of attributes, one for an ideal option and the other for a notional opposing force, to determine maximum and floor effectiveness values that define the upper and lower boundaries of a 0-to-1 effectiveness scale for each mission. The raw effectiveness levels are normalized using these boundary values to obtain the overall mission effectiveness of each option (E[f,m]). This calculation is performed in each run of the evaluation model, so the attributes of the ideal option are somewhat different each time, since they depend on the attributes of all the options, which are derived from uncertain component characteristic ratings. To avoid additional complexity, however, there is no such uncertainty in the characteristics of an opposing force; its attributes, and the floor effectiveness, are fixed. (The characteristics and attributes of the opposing forces assigned to each mission in the two time frames are described in Appendix A.)

The median mission effectiveness values for the near-term options are shown in Table 8.3, and are depicted in Figure 8.3 with their 90-percent confidence intervals (i.e., $5^{th}$ to $95^{th}$ percentile ranges). These mission effectiveness values are all derived from the same set of attributes for each option; the attribute values are just weighted differently for each mission. Thus, it is not surprising that the pattern of effectiveness results is similar across missions. In particular, heavy and medium are vying for the top spot in every mission, with air + SOF consistently in third place, light in fourth, and air only in fifth. The variation in these outcomes due to performance uncertainties differed for each option, but was fairly consistent across missions. This effectiveness uncertainty, as represented by the confidence intervals in Figure 8.3, was greatest

for the air only option, less for the light and air + SOF options, and smallest for the two leading options, medium and heavy.

**Table 8.3**

**Median Mission Effectiveness Levels of Near Term Force Options**

| Mission | Force Option | | | | |
|---|---|---|---|---|---|
| | Heavy | Medium | Light | Air Only | Air + SOF |
| Halt | 0.951 | 0.934 | 0.652 | 0.550 | 0.816 |
| Defend | 0.928 | 0.887 | 0.448 | 0.292 | 0.709 |
| Protect | 0.902 | 0.913 | 0.525 | 0.307 | 0.737 |
| Evict | 0.982 | 0.924 | 0.611 | 0.571 | 0.802 |
| Raid | 0.922 | 0.919 | 0.507 | 0.354 | 0.738 |
| Stabilize | 0.905 | 0.926 | 0.556 | 0.319 | 0.756 |

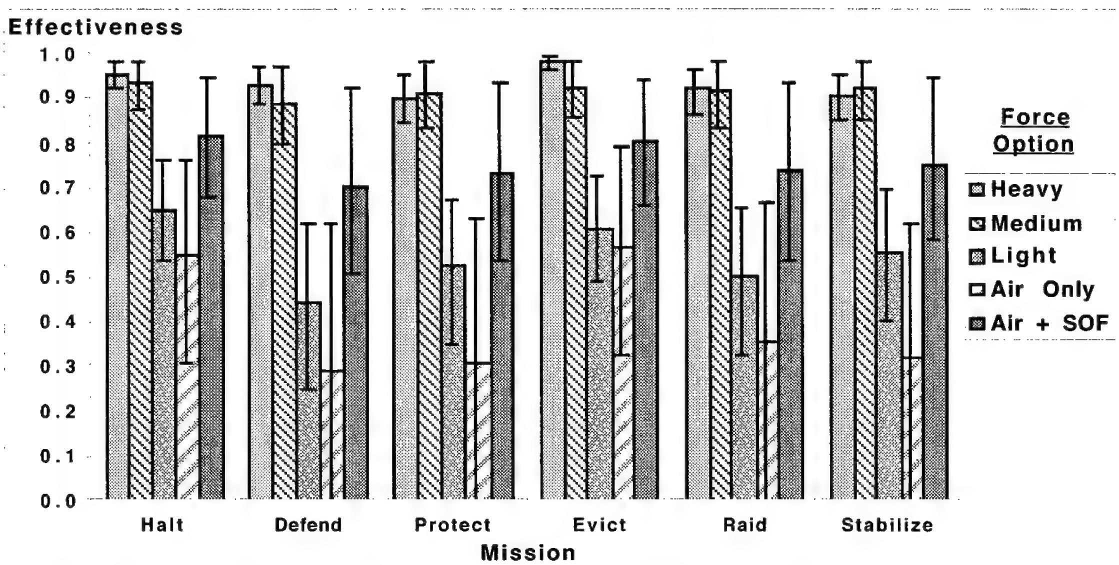



**Figure 8.3. Mission Effectiveness of Near-Term Force Options**

The effectiveness results for the far-term options, which are shown in Table 8.4 and depicted in Figure 8.4, are equally interesting. As in the near term, the order of the options is the same in all six missions, although the effectiveness levels are somewhat different relative to one another. The future medium option is clearly the most effective in every mission. The lean heavy, advanced air + SOF and enhanced light options follow in order, with their median values closest together in the low-intensity missions, protect and stabilize. The air only mission

is clearly the least effective, falling well below all of the other options in every mission. The degree of uncertainty in these outcomes also varies considerably. There is very little variation in the effectiveness of the future medium option because it has the highest median level of every attribute except deployability (see Figure 8.2), so it is often very similar to the ideal option used to normalize the effectiveness scale. The next three options—lean heavy, advanced air + SOF and enhanced light—have a moderate amount of variance, while the last-place advanced air only option varies the most.

**Table 8.4**

**Median Mission Effectiveness Levels of Far Term Force Options**

| Mission | Force Option | | | | |
|---|---|---|---|---|---|
| | Lean Heavy | Future Medium | Enhanced Light | Advanced Air Only | Advanced Air + SOF |
| Halt | 0.841 | 0.980 | 0.725 | 0.556 | 0.775 |
| Defend | 0.813 | 0.982 | 0.666 | 0.454 | 0.725 |
| Protect | 0.775 | 0.971 | 0.693 | 0.426 | 0.731 |
| Evict | 0.873 | 0.995 | 0.661 | 0.550 | 0.734 |
| Raid | 0.790 | 0.972 | 0.662 | 0.464 | 0.717 |
| Stabilize | 0.761 | 0.977 | 0.696 | 0.394 | 0.721 |

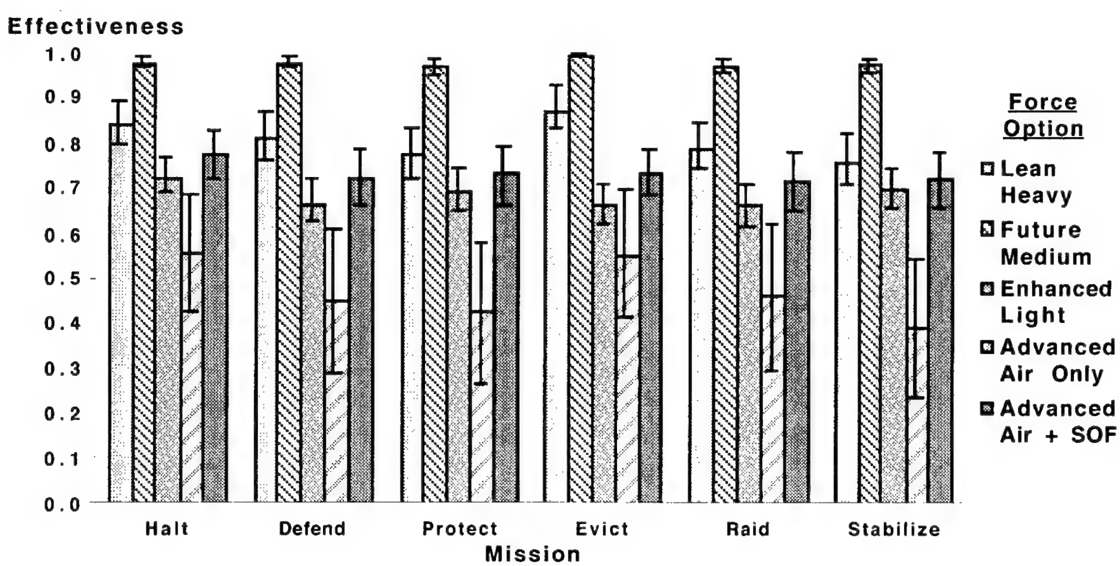



**Figure 8.4. Mission Effectiveness of Far-Term Force Options**

In both time frames, the confidence intervals in the effectiveness of some options overlap. In the near term, the confidence intervals of heavy and medium overlap substantially, as do those of light and air only. The air + SOF interval overlaps with those of every other option to at least some extent. In the far term, the future medium confidence intervals do not overlap with those of any other option. The intervals for lean heavy, enhanced light and advanced air + SOF overlap with each other, particularly in the low-intensity missions. The advanced air only option's confidence intervals only overlap with those of one other option—enhanced light—in the evict mission.

The amount of visible overlap does not, however, tell the whole story. Each option is composed of various system and operational components. Some component systems, namely the aircraft and missiles, and operational concepts appear in more than one option, in the same time frame. Since the characteristics of these components are assigned at random in each simulation run, the option characteristics derived from them are not be independent, and the effectiveness distributions of the options are correlated with each other. Thus, the best way to gauge how much the outcome distributions in each time frame really overlap is to compare the effectiveness rankings of all the options in every individual run.

## 8.3 RANK FREQUENCIES

Table 8.5 shows the results of this sort of comparison for the near-term options. For every mission, it indicates how often in the 100 runs conducted for the analysis each option placed in every possible rank. In the halt mission, for example, the heavy option had the highest effectiveness value in 61 runs, the second highest in 35 runs, and the third highest in 4 runs. Table 8.6 shows the same rank frequency results for the far-term options, again for each of the six missions. These rank frequencies are the baseline from which the rank shifts that are used to evaluate the impact of perturbations and option alterations are measured in the exploration phase.

**Table 8.5**

**Baseline Rank Frequencies of Near-Term Force Options in Each Mission**

| | Rank Frequency of Force Option for Each Mission | | | | | | | | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Heavy | | | | | Medium | | | | | Light | | | | | Air Only | | | | | Air + SOF | | | | |
| **Mission** | 1 | 2 | 3 | 4 | 5 | 1 | 2 | 3 | 4 | 5 | 1 | 2 | 3 | 4 | 5 | 1 | 2 | 3 | 4 | 5 | 1 | 2 | 3 | 4 | 5 |
| Halt | 61 | 35 | 4 | 0 | 0 | 34 | 62 | 4 | 0 | 0 | 0 | 0 | 3 | 74 | 23 | 0 | 0 | 3 | 20 | 77 | 5 | 3 | 86 | 6 | 0 |
| Defend | 67 | 29 | 4 | 0 | 0 | 28 | 67 | 5 | 0 | 0 | 0 | 0 | 3 | 74 | 23 | 0 | 0 | 2 | 21 | 77 | 5 | 4 | 86 | 5 | 0 |
| Protect | 41 | 48 | 11 | 0 | 0 | 53 | 45 | 2 | 0 | 0 | 0 | 0 | 3 | 83 | 14 | 0 | 0 | 1 | 13 | 86 | 6 | 7 | 83 | 4 | 0 |
| Evict | 88 | 12 | 0 | 0 | 0 | 9 | 85 | 6 | 0 | 0 | 0 | 0 | 3 | 59 | 38 | 0 | 0 | 7 | 31 | 62 | 3 | 3 | 84 | 10 | 0 |
| Raid | 49 | 44 | 7 | 0 | 0 | 46 | 50 | 4 | 0 | 0 | 0 | 0 | 3 | 74 | 23 | 0 | 0 | 2 | 21 | 77 | 5 | 6 | 84 | 5 | 0 |
| Stabilize | 39 | 50 | 11 | 0 | 0 | 55 | 43 | 2 | 0 | 0 | 0 | 0 | 3 | 85 | 12 | 0 | 0 | 1 | 11 | 88 | 6 | 7 | 83 | 4 | 0 |

NOTE: These are raw frequencies from a sample of 100 Monte Carlo runs.

The rank frequencies in Table 8.5 confirm the near-term option rankings that are apparent in Figure 8.3: air only in fifth, light in fourth, air + SOF in third, and heavy and medium both vying for first, in every mission. The interesting aspect of these frequencies is how they differ across missions. The heavy option is dominant in the evict mission, placing first in 88 of the 100 runs, and is also strong in the halt and defend missions, with over 60 of the firsts. It is, however, much weaker in the other three less traditional missions, only winning in about half of the runs for the raid mission, and about 40 in the two low-intensity missions, protect and stabilize. The medium option rank frequencies essentially mirror those of the heavy option; medium wins a slim majority of the runs in the protect and stabilize missions, and is a close contender in the raid mission, but only wins about 30 runs in the halt and defend missions, and less than 10 in the evict mission. The air + SOF mission placed third in over 80 runs for every mission, and in the remaining runs it was able to beat heavy and/or medium to place first or second several times, but also placed fourth a number of times, doing slightly better in the low-intensity missions and worst in the evict mission. The light option placed third a few times in every mission, but for the most part vied with the air only option for fourth place, prevailing in a majority of runs for every mission, doing the worst in the evict mission and the best in the low-intensity missions. The rank frequencies of the air only option mirrored those of

the light option, except that in the evict mission it placed fourth in over 30 of the 100 runs, and was even able to beat air + SOF to place third 7 times.

### Table 8.6

### Baseline Rank Frequencies of Far-Term Force Options in Each Mission

| | Rank Frequency of Force Option for Each Mission | | | | | | | | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Lean Heavy | | | | | Future Medium | | | | | Enhanced Light | | | | | Advanced Air Only | | | | | Advanced Air + SOF | | | | |
| **Mission** | 1 | 2 | 3 | 4 | 5 | 1 | 2 | 3 | 4 | 5 | 1 | 2 | 3 | 4 | 5 | 1 | 2 | 3 | 4 | 5 | 1 | 2 | 3 | 4 | 5 |
| Halt | 0 | 93 | 7 | 0 | 0 | 100 | 0 | 0 | 0 | 0 | 0 | 0 | 14 | 83 | 3 | 0 | 0 | 0 | 3 | 97 | 0 | 7 | 79 | 14 | 0 |
| Defend | 0 | 97 | 3 | 0 | 0 | 100 | 0 | 0 | 0 | 0 | 0 | 0 | 14 | 83 | 3 | 0 | 0 | 0 | 3 | 97 | 0 | 3 | 83 | 14 | 0 |
| Protect | 0 | 85 | 11 | 4 | 0 | 100 | 0 | 0 | 0 | 0 | 0 | 1 | 27 | 72 | 0 | 0 | 0 | 0 | 0 | 100 | 0 | 14 | 62 | 24 | 0 |
| Evict | 0 | 100 | 0 | 0 | 0 | 100 | 0 | 0 | 0 | 0 | 0 | 0 | 5 | 82 | 13 | 0 | 0 | 2 | 11 | 87 | 0 | 0 | 93 | 7 | 0 |
| Raid | 0 | 93 | 7 | 0 | 0 | 100 | 0 | 0 | 0 | 0 | 0 | 0 | 15 | 82 | 3 | 0 | 0 | 0 | 3 | 97 | 0 | 7 | 78 | 15 | 0 |
| Stabilize | 0 | 82 | 14 | 4 | 0 | 100 | 0 | 0 | 0 | 0 | 0 | 6 | 31 | 63 | 0 | 0 | 0 | 0 | 0 | 100 | 0 | 12 | 55 | 33 | 0 |

NOTE: These are raw frequencies from a sample of 100 Monte Carlo runs.

The rank frequencies for the far-term options in Table 8.6 reflect the relative effectiveness results shown in Figure 8.4. The confidence intervals of these options over lap less than those of the near-term options, so it is not surprising that each option's rank frequencies are more concentrated on a single rank. The future medium option always placed first. The lean heavy option placed second every time in the evict mission, and almost every time in all the other missions; in the protect and stabilize missions it placed second the least often, about 80-85 percent of the time, and even placed fourth in a few runs. Similarly, the advanced air only option always placed fifth in the two low-intensity missions, and only placed fourth a few times in all of the other missions, except evict, where its fourth place frequency was over 10 and it even placed third in a couple of runs. Enhanced light and advanced air + SOF were the only options that had any substantial spread in their rankings. The advanced air + SOF option placed third in a majority of the runs for every mission. In the evict mission it only slipped back to fourth 7 times, but never placed second. In the halt, defend and raid missions it placed third in about 80 runs, fourth in 14 or 15 runs, and second in the remaining few runs. Its rankings were most diffuse in the protect and stabilize missions; it placed second over 10 times, but placed in fourth much

more often as well, so that its third place frequency was only about 60. The higher effectiveness of the enhanced light option in these low-intensity missions was the cause for this spreading; this option pushed up from fourth to third place in these mission in about 30 of the 100 runs, and even managed to place second once in the protect mission and 6 times in the stabilize mission. In the other missions it placed fourth in 82 or 83 runs, and second in most of the rest, except for evict, where it placed fifth more often.

## 8.4 OPTION PREFERENCE FREQUENCIES

Clearly, when the effectiveness confidence intervals of two or more options overlap, these options are not always ranked in the same order in every run, nor are their rank frequencies always the same in every mission. Indeed, the results in Tables 8.5 and 8.6 show the extent to which differences in effectiveness overlaps affect the rank frequency distributions for each mission. While rank frequencies show how options place in the group, they do not indicate how two options compare one-on-one. The effectiveness of key option pairs, like those suggested in Chapter 5 for each time frame, must be compared directly. Specifically, the effectiveness levels are compared in each Monte Carlo run, and the frequency with which the first option is more effective than the second is calculated and normalized. These preference frequencies are presented in Table 8.7 for the near term, and in Table 8.8 for the far term. The results of these selected comparisons are discussed below.

### Near-Term Option Comparisons

*Medium Versus Heavy.* The medium and heavy options had similar levels of effectiveness in all six missions, with considerable overlap in their confidence intervals in most cases. In the two low-intensity missions, protect and stabilize, medium was more effective than heavy in about 60 of the 100 Monte Carlo runs. And, in the raid mission, medium did almost as well as heavy, with greater effectiveness in just under half of the runs. Heavy did best in evict, an offensive

high-intensity mission, where medium was more effective in less than 10 percent of runs. Heavy was also more effective more often than medium in the remaining defensive missions, halt and defend, in which medium only won 36 and 30 percent of the time, respectively. Overall, these results imply that, in the near term, a medium-weight force is favored over a traditional heavy armored force in low-intensity missions, although there are still a substantial range of circumstances in these missions where the heavy force would do at least as well.

**Table 8.7**

**Preference Frequencies for Selected Pairs of Near-Term Options**

| Option Pair, with Preference | Normalized Frequency of Preference for Each Mission | | | | | |
|---|---|---|---|---|---|---|
| | Halt | Defend | Protect | Evict | Raid | Stabilize |
| Medium vs. Heavy | 0.36 | 0.30 | 0.58 | 0.09 | 0.49 | 0.60 |
| Medium vs. Light | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 |
| Light vs. Air Only | 0.77 | 0.77 | 0.86 | 0.62 | 0.77 | 0.88 |
| Air + SOF vs. Air Only | 0.97 | 0.98 | 0.99 | 0.93 | 0.98 | 0.99 |
| Air + SOF vs. Light | 0.97 | 0.97 | 0.97 | 0.97 | 0.97 | 0.97 |
| Air + SOF vs. Medium | 0.06 | 0.07 | 0.07 | 0.06 | 0.07 | 0.07 |
| Air + SOF vs. Heavy | 0.07 | 0.07 | 0.12 | 0.03 | 0.09 | 0.12 |

*Medium Versus Light.* The effectiveness distributions of the medium and light options did not overlap for any of the six missions. As a result, medium was always more effective than light in every mission. This shows that, in terms of overall effectiveness, a near-term medium-weight force is clearly favored over a current light infantry force in a wide range of missions.

*Light Versus Air Only.* The light option was generally more effective than the air only option across all six missions, although there was some overlap in the effectiveness distributions of these two options. This overlap was smallest for protect and stabilize, the two low-intensity missions, where light had higher effectiveness levels over 85 percent of the time. The margin of victory was smallest in the evict mission, where light only won just over 60 percent of the runs. In the remaining missions, raid, halt and defend, the light option prevailed over 75 percent of the time. Thus, like a medium-weight force, a light infantry

force is strongest in low-intensity missions, but weakest in offensively oriented high-intensity missions, at least in comparison to an all air and missile force.

*Air + SOF Versus Air Only.* There is only a small amount of overlap in the effectiveness distributions of the air + SOF and air only options. This limited overlap resulted in higher effectiveness for air + SOF in well over 90 percent of the runs for all six missions, dipping below 95 percent only once for the evict mission. The few persistent victories for air only represent a limited set of circumstances in which the disadvantages of the added systems—SOF teams and A-10 aircraft—are large enough to outweigh their benefits for air + SOF.

*Air + SOF Versus Light.* The air + SOF option has a similar relationship with the light option; it is consistently more effective, winning 97 percent of the time in every mission. The small number of losses by the air + SOF option are again attributable to a small range of unfavorable, but unlikely combinations of circumstances.

In addition to the option pairs associated with these five questions, there are two other pairs of near-term options that are worth comparing: air + SOF versus medium and versus heavy. The near-term mission effectiveness results in Figure 8.3 show that the confidence intervals of air +SOF overlap with those of these two leading options, and the rank frequencies in Table 8.5 show that air + SOF does in fact place first or second in several of the 100 runs, so the preference frequencies for these two extra comparisons are also included in Table 8.7. The question associated with these two added comparisons are discussed here along with the corresponding results.

*Air + SOF Versus Medium.* The air + SOF option is consistently less effective than the medium option across all missions, but was able to win several percent of the time in every mission. This indicates that there is a limited set of circumstances in which aircraft and missiles, augmented by SOF teams, could be a bit more effective than a near-term medium-weight force.

*Air + SOF Versus Heavy.* Similarly, the air + SOF option is generally less effective than the heavy option. Against this option, however, air + SOF was able to make greater inroads in the low-intensity missions, protect and stabilize, where it won 12 of 100 runs. Following a familiar pattern, it also did a bit better in the raid mission, with 9 wins, but much worse in the evict mission, with only 3 wins.

**Table 8.8**

**Frequency of Preferences Between Selected Pairs of Far-Term Options**

| Option Pair, with Preference | Normalized Frequency of Preference for Each Mission | | | | | |
|---|---|---|---|---|---|---|
| | Halt | Defend | Protect | Evict | Raid | Stabilize |
| F. Medium vs. L. Heavy | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 |
| F. Medium vs. E. Light | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 |
| E. Light vs. A. A. Only | 0.97 | 0.97 | 1.00 | 0.87 | 0.97 | 1.00 |
| A. A. + SOF vs. A. A. Only | 1.00 | 1.00 | 1.00 | 0.98 | 1.00 | 1.00 |
| A. A. + SOF vs. E. Light | 0.86 | 0.86 | 0.76 | 0.95 | 0.85 | 0.66 |
| E. Light vs. L. Heavy | 0.00 | 0.00 | 0.05 | 0.00 | 0.00 | 0.09 |
| A. A. + SOF vs. L. Heavy | 0.07 | 0.03 | 0.14 | 0.00 | 0.07 | 0.13 |

## Far-Term Option Comparisons

*Future Medium Versus Lean Heavy.* The future medium force is clearly more effective than the lean heavy option in every mission, winning every single run. This implies that, overall, a future medium-weight force, built around a family of highly capable future combat vehicles, would represent a broad improvement over a leaner, modernized heavy armored force.

*Future Medium Versus Enhanced Light.* Similarly, the future medium option also wins over the enhanced light option in every mission. This implies that even a significantly improved light infantry force would still not be able to match the far-term medium-weight force in terms of overall effectiveness.

*Enhanced Light Versus Advanced Air Only.* The enhanced light option is, however, more effective than an advanced air only option under almost all circumstances. This supremacy is clear in the low-intensity missions, but is weaker in the offensive high-intensity evict mission, where the advanced air only

option was able to prevail over 10 percent of the time. Thus, air only forces, while less effective than other rapid-response forces with a substantial ground presence, may do better in a small range of high-intensity situations.

*Advanced Air + SOF Versus Advanced Air Only.* The many extra systems in the advanced air + SOF, together with its greater operational flexibility, make it unquestionably more effective than the advanced air only option in every mission, which only managed to win two runs in evict.

*Advanced Air + SOF Versus Enhanced Light.* There is considerable overlap in the effectiveness confidence intervals for these two options, but advanced air + SOF prevails most frequently in every mission. It is especially strong in the evict mission, winning 95 percent of the runs, but is weakest in the two low-intensity missions, losing to enhanced light about a quarter of the time for protect and about a third of the time for stabilize.

As in the near term, the effectiveness and rank frequency results suggest that two additional comparisons might be worthwhile. Figure 8.4 shows that the lean heavy option's confidence intervals overlap with those of the enhanced light option for the two low-intensity missions, and with those of the advanced air + SOF option for every mission except evict. The rank frequencies in Table 8.6 confirm that these three options were vying for second and third place, especially in the low-intensity protect and stabilize missions. The questions associated with these two extra comparisons are presented here along with a discussion of their preference frequency results, which are included in Table 8.8.

*Enhanced Light Versus Lean Heavy.* The enhanced light option is undoubtedly less effective than the lean heavy option in all four of the non-low-intensity missions, where it did not win a single run. In the protect and stabilize missions, however, it did win 5 and 9 of the 100 runs, respectively. Thus, in a narrow range of low-intensity situations, a much-improved light infantry force may be slightly better than a modernized heavy armored force, but would otherwise be consistently less effective.

*Advanced Air + SOF Versus Lean Heavy.* The advanced air + SOF option, which was consistently more effective than enhanced light, did even better against the lean heavy option in the two low-intensity missions, although it still only prevailed 13 or 14 percent of the time. This option also had some success in each of the other missions except evict, winning 7 of 100 runs for halt and raid, but only 3 runs for defend. This indicates that there are small but diverse range of circumstances in which a force consisting of advanced aircraft and long-range missile systems, together with SOF teams, could be even more effective than a lean, modernized heavy armored force.

## 8.5 CONCLUDING REMARKS

This chapter described the evaluation results, which were calculated in phase three of the HIMAX demonstration analysis. These results included the attribute values and mission effectiveness outcomes for each option, as well as the rank frequencies of all the options, and the preference frequencies for selected option pairs. Chapter 9 describes the results of the fourth phase—prioritization—where options are screened and ranked, before being scored in terms of their overall strategic value, and then compared using surface plots that show how sensitive option preferences are to strategic uncertainty.

# 9. PRIORITIZATION

In the fourth phase of the HIMAX process, the effectiveness results for the force options in each time frame are prioritized in a variety of ways. First, the options are screened using three different techniques: dominance, attitude orientation, and sequential elimination. The options are then compared in terms of their overall strategic value, which is a weighted average of their effectiveness in every mission. Because they are so uncertain, the missions weights in this calculation are parameterized based on the offensive or defensive orientation of the mission, and its level of intensity. The resulting parameters define a space in which preference surfaces are drawn for selected pairs of options (which must have overlapping strategic value distributions). Finally, the strategic values of the options are compared in a few illustrative scenarios that represent different types of future security environments, and are associated with specific points in the parameter space.

## 9.1 OPTION SCREENING

Before calculating an overall score for each option that enables strengths in some areas to compensate for weaknesses in others, the following three non-compensatory screening techniques are applied to see if they yield any useful insights: dominance, attitude orientation, and sequential elimination. A strict type of dominance approach is used, in which an option is only dominated if another option has higher values for all six force attributes. This ensures that all dominance relationships are independent of how important the attributes are relative to one another in various missions, since a dominated option will always be less effective than one of the other options no matter how the attributes are weighted in any of the mission effectiveness calculations. Two different attitude orientation methods are applied: the optimistic maximax, which selects the option with the highest effectiveness in its best mission; and the pessimistic

maximin, which selects the option with the highest effectiveness in its worst mission. The sequential elimination technique used here, lexicographic selection, designates one mission as the most important, and then chooses the option that is most effective in that mission, considering other missions only if there is a tie.

### Near-Term Screening Results

Table 9.1 shows the results of applying these three screening methods to the near-term options. A normalized frequency for each option indicates how often (in the Monte Carlo runs) the option met the associated screening criterion. The criterion and the near-term results for each method are discussed below.

*Non-Dominance.* The screening criterion for dominance is its opposite, non-dominance; an option passes the screening if it is not dominated by any other option. Among the near-term options, only heavy was never dominated, although medium was close, with a non-domination rate of 98 percent. Air only, by contrast, was almost always dominated by at least one of the other options, escaping domination in only one of the 100 runs. Light and even air + SOF were also dominated quite frequently, with non-domination rates of 14 and 28 percent, respectively.

*Maximax.* The screening process for maximax selects only the option that has the highest effectiveness in its best mission, comparing the options based on their highest effectiveness value for any of the six missions. Unlike the non-dominance frequencies, these sum to one since there can only be one maximax winner in each run. The heavy option was the maximax choice 86 percent of the time, while the medium option won just 10 percent of the time, and air + SOF won the other 4 percent; neither light nor air only were ever selected.

*Maximin.* The maximin screening process is, of course, essentially the same as that of maximax, except that the options are compared based on their lowest (rather than their highest) effectiveness value for any of the six missions. The results, however, are a bit different. Heavy was the maximin choice most often,

but was only selected 55 percent of the time, while medium was selected in 40 percent of the runs. As in the maximax screening, light and air only were never selected, and air + SOF was chosen only rarely—5 percent of time in this case.

*Lexicographic.* The lexicographic screening criterion selects the option that is most effective in the mission designated as most important. Table 9.1 shows the results of this screening when each of the six missions are given this "top" designation. Note that these results are the normalized equivalents of the rank frequencies shown in Table 8.5 for first place. The medium option is selected in a slim majority of runs if either of the two low-intensity missions are designated as the top mission, but the heavy option is also selected about 40 percent of the time. Moreover, heavy is selected more frequently than medium if any of the other four missions is given this designation; heavy wins only a few percent more runs if the raid mission is selected, a total of over 60 percent if halt or defend are chosen, and almost 90 percent if evict is the top mission.

**Table 9.1**

**Screening Results for Near Term Force Options**

| *Screening Technique* | **Normalized Frequency of Force Option Meeting Criterion** | | | | |
|---|---|---|---|---|---|
| **Criterion** | Heavy | Medium | Light | Air Only | Air + SOF |
| *Non-Dominance* Not dominated by any option | 1.00 | 0.98 | 0.14 | 0.01 | 0.27 |
| *Maximax* Most effective in its best mission | 0.86 | 0.10 | 0.00 | 0.00 | 0.04 |
| *Maximin* Most effective in its worst mission | 0.55 | 0.40 | 0.00 | 0.00 | 0.05 |
| *Lexicographic* Most effective in top mission... | | | | | |
| Halt | 0.61 | 0.34 | 0.00 | 0.00 | 0.05 |
| Defend | 0.67 | 0.28 | 0.00 | 0.00 | 0.05 |
| Protect | 0.41 | 0.53 | 0.00 | 0.00 | 0.06 |
| Evict | 0.88 | 0.09 | 0.00 | 0.00 | 0.03 |
| Raid | 0.49 | 0.46 | 0.00 | 0.00 | 0.05 |
| Stabilize | 0.39 | 0.55 | 0.00 | 0.00 | 0.06 |

### Far-Term Screening Results

The far-term screening results are far less interesting, so they are not discussed here in as much detail. As the rank frequency results in Table 8.6 indicate, the future medium option is so clearly favored over all of the other missions that it is unchallenged as the most effective option in every mission. As a result, this option is selected with a normalized frequency of 1 by all of the screening techniques. The non-dominance results are the only ones that deserve a closer look. Of course, future medium was never dominated, but interestingly enough, enhanced light was never dominated either, since it was always more deployable or more sustainable than future medium, as the attribute confidence intervals in Figure 8.2 indicate. Advanced air + SOF also avoided domination almost 90 percent of the time because of its similarly high level of deployability. Lean heavy, however, is dominated in all but 4 of the 100 runs because its distribution of attributes is fairly balanced, like that of future medium, though at consistently lower levels. Less surprisingly, the advanced air only option was always dominated by at least one option.

## 9.2 PARAMETERIZED STRATEGIC VALUE COMPARISONS

An overall score is calculated for each option by taking a weighted average of its effectiveness across all six missions. This score is a measure of strategic value, so the weight placed on each mission represents its relative importance strategically. Each unique combination of weights corresponds to a different type of future in which the prevalence and risks of the missions warrant that particular distribution of importance. Because of the tremendous uncertainty in the future security environment, however, the best way to examine and compare strategic value is to parameterize the mission effectiveness weights, rather than making a single "best-guess" estimate at their values. This approach provides a picture that encompasses a wide range of futures simultaneously, thus making it easier to visualize the impact that changes in mission emphasis have on the

strategic value of a force. Especially effective are preference surfaces that indicate how often one option is more strategically valuable than another, in terms of a normalized frequency.

### Parameterization of Strategic Mission Weights

A minimum of five parameters are needed to fully characterize the six strategic weights associated with these missions (SW[m]) in the additive strategic value calculation described in Chapter 3, since these weights must sum to one. Two additional assumptions further reduce the number of parameters needed to three, which then form the dimensions of a space in which preference surfaces can be drawn. The parameter definitions, and the two extra assumptions, draw on differences in the orientation and intensity of the missions. Three missions are offensively oriented, and the other three are defensively oriented. Within each of these subsets, one mission is high-intensity, another is mid-intensity, and the final one is low-intensity.

The three parameters specify the ratios between the strategic weights on: (1) offensive missions and defensive missions; (2) low-intensity missions and non-low-intensity missions (i.e., high-intensity and mid-intensity missions); and (3) high-intensity missions and mid-intensity missions. These three parameters, $P_1$, $P_2$ and $P_3$, respectively, are defined in terms of the strategic mission weights:

$$
\begin{aligned}
P_1 &= \frac{\mathtt{SW[evict] + SW[raid] + SW[stabilize]}}{\mathtt{SW[halt] + SW[defend] + SW[protect]}}, \\
P_2 &= \frac{\mathtt{SW[stabilize]}}{\mathtt{SW[evict] + SW[raid]}} = \frac{\mathtt{SW[protect]}}{\mathtt{SW[halt] + SW[defend]}}, \\
P_3 &= \frac{\mathtt{SW[evict]}}{\mathtt{SW[raid]}} = \frac{\mathtt{SW[halt]}}{\mathtt{SW[defend]}}.
\end{aligned}
\tag{9.1}
$$

The two extra assumptions, which are included in the definitions of $P_2$ and $P_3$, require the mission intensity ratios among the offensive and defensive missions to be the same. As a result, the ratio between the weights of a pair of offensive

and defensive missions with the same intensity is always $P_1$. These relationships are apparent when the mission weights are expressed in terms of the parameters:

$$
\begin{aligned}
\text{sw[halt]} &= \frac{P_3}{(1 + P_1)(1 + P_2)(1 + P_3)}, \\
\text{sw[defend]} &= \frac{1}{(1 + P_1)(1 + P_2)(1 + P_3)}, \\
\text{sw[protect]} &= \frac{P_2}{(1 + P_1)(1 + P_2)}, \\
\text{sw[evict]} &= \frac{P_1 \cdot P_3}{(1 + P_1)(1 + P_2)(1 + P_3)}, \\
\text{sw[raid]} &= \frac{P_1}{(1 + P_1)(1 + P_2)(1 + P_3)}, \\
\text{sw[stabilize]} &= \frac{P_1 \cdot P_2}{(1 + P_1)(1 + P_2)}.
\end{aligned}
\qquad (9.2)
$$

## Visualization of Option Preference Surfaces

These parameters form the dimensions of a space in which every point represents a different type of future security environment. Surfaces drawn in this parameter space represent the preferences between two options, based on their overall strategic values in the Monte Carlo simulation runs. Such surfaces help visualize the impact of strategic uncertainty on option preferences.[70] They are constructed by calculating the normalized preference frequency at a number of representative points, which span a wide range of parameter values, and then interpolating between them.

Preference surfaces are depicted here in a sequence of three contour plots, each representing a different parallel slice through the parameter space. These

---

[70] The strategic value of each option could be plotted in this space to form a strategic value surface. Such surfaces would be difficult to compare, however, and would not provide much additional insight. The strategic value levels would not vary that much from point to point, since the mission effectiveness levels are so similar across missions, and the uncertainty in these values may even exceed this spatial variation. Differences in the strategic value of various options could also be calculated, but their distributions would be large in comparison to their magnitudes, and the scale would not have much meaning.

slices hold $P_1$, the offensive-to-defensive ratio, at fixed values of 1/3, 1 and 3. In the first slice defensive missions are three times as important as offensive missions. Offensive and defensive missions are equally important in the middle slice. And, in the third slice, offensive missions are three times as important as defensive missions. In each of these contour plot slices, a log scale ranging from 1/100 to 100 is used for both of the other parameter axes: $P_2$, the low-to-non-low-intensity ratio, on the x-axis; and $P_3$, the high-to-mid-intensity ratio, on the y-axis.

Obviously, these types of surface plots are most interesting when the pairs of options have overlapping effectiveness distributions, and their preference frequencies differ somewhat across missions. As the mission preference frequencies in Table 8.7 show, two pairs of near-term options clearly meet these criteria, and are examined here: medium versus heavy, and light versus air only. As Table 8.8 shows, the effectiveness distributions of the far-term options do not overlap as much, so the choices in this time frame are less clear. Two pairs do, however, have enough overlap and variation to warrant examination: advanced air + SOF versus enhanced light, and versus lean heavy.

*Medium Versus Heavy.* The preference surface for this near-term option pair is depicted in Figure 9.1. In the defensive slice, the preference frequency depends only on the low-to-non-low-intensity ratio; medium is preferred to heavy in a slim majority of runs if low-intensity missions are more than about twice as important as non-low-intensity missions. Even if low-intensity missions are less important, the medium option still wins over 30 percent of the time. But, the other two slices show clearly that the high-to-mid-intensity ratio becomes a significant factor if offensive missions are more important. In particular, the preference frequency for medium drops below 30 percent in the upper left corner, where high-intensity missions are the most important.

*Light Versus Air Only.* The shape of the preference surface for this pair of near-term options is similar to the medium-versus-heavy surface, except that the frequency levels are considerably higher and a bit more consistent in this case.

The contour plots for this comparison in Figure 9.2 show that the preference frequency is always between 0.60 and 0.90. In fact, it only exceeds 0.80 if the non-low-intensity missions are less than two to three times as important as the low-intensity missions, and drops below 0.70 only if offensive missions are at least as important as defensive missions, and high-intensity missions are much more important than the other missions.

*Advanced Air + SOF Versus Enhanced Light.* The preference surface for this pair of far-term options is shown in Figure 9.3. The advanced air + SOF option is always more strategically valuable than the enhanced light option in a large majority of cases. In every future, this preference frequency increases as low-intensity missions become less important, surpassing 0.80 as the low-to-non-low-intensity ratio drops below about 1. If offensive missions are considerably more important, the preference frequency even exceeds 0.90 in the upper left corner, where high-intensity missions are extremely important, but drops below 0.70 on the right side, where low-intensity missions are more important.

*Advanced Air + SOF Versus Lean Heavy.* The advanced air + SOF option is almost always less strategically valuable than the lean heavy option. The preference surface for this option pair in Figure 9.4 shows that the frequency of advanced air + SOF being preferred to lean heavy is somewhat higher if low-intensity missions are more important, but never exceeds 0.15. Indeed, this frequency approaches zero if high-intensity missions are very important, independent of whether the emphasis is on offensive or defensive missions.

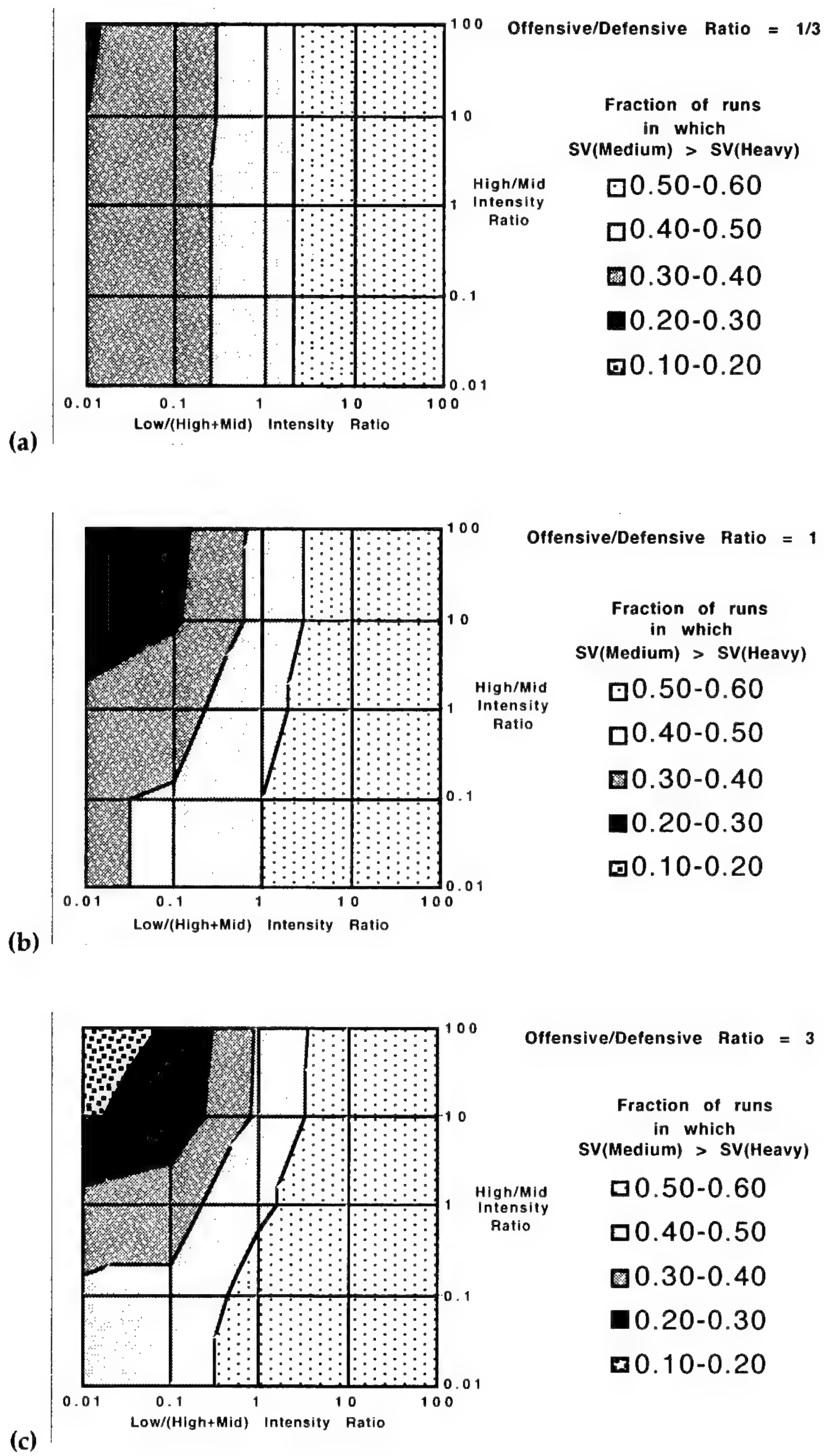



**Figure 9.1. Strategic Value Preference Surface for Medium over Heavy in the Near Term when: (a) defensive missions are more important; (b) offensive and defensive missions are equally important; and (c) offensive missions are more important.**

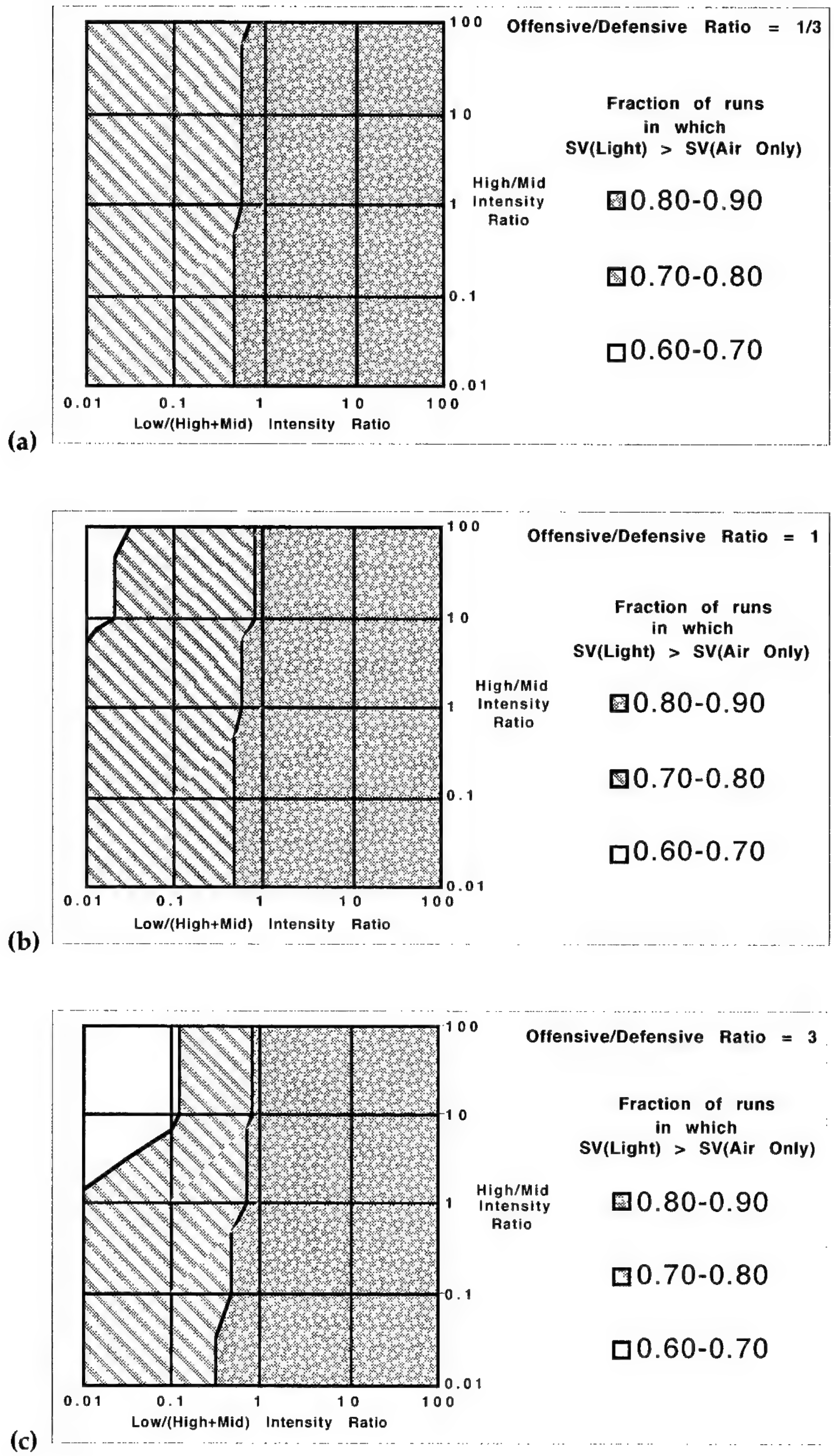



**Figure 9.2. Strategic Value Preference Surface for Light over Air Only in the Near Term when: (a) defensive missions are more important; (b) offensive and defensive missions are equally important; and (c) offensive missions are more important.**

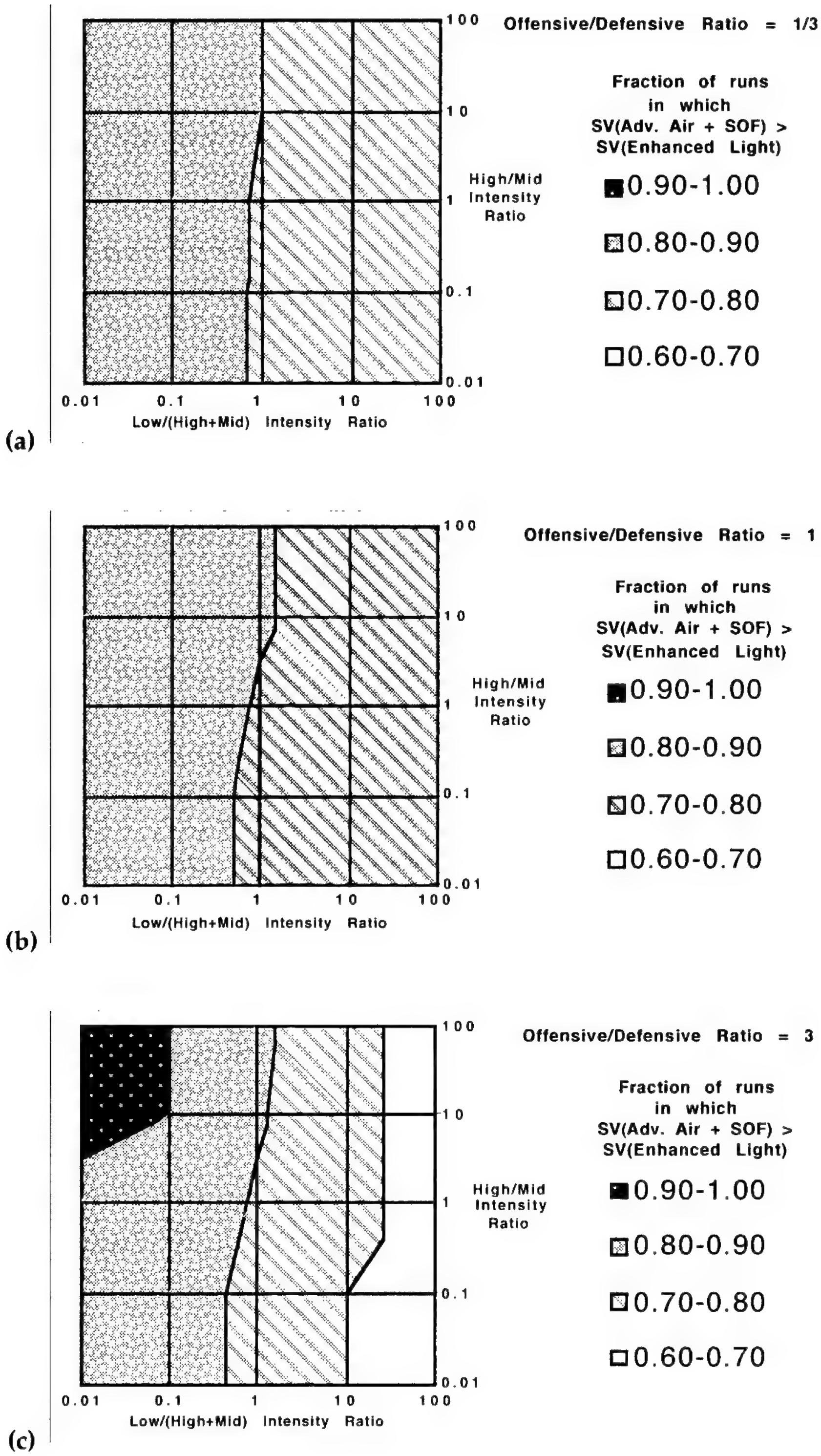



**Figure 9.3. Strategic Value Preference Surface for Advanced Air + SOF over Enhanced Light in the Far Term when: (a) defensive missions are more important; (b) offensive and defensive missions are equally important; and (c) offensive missions are more important.**

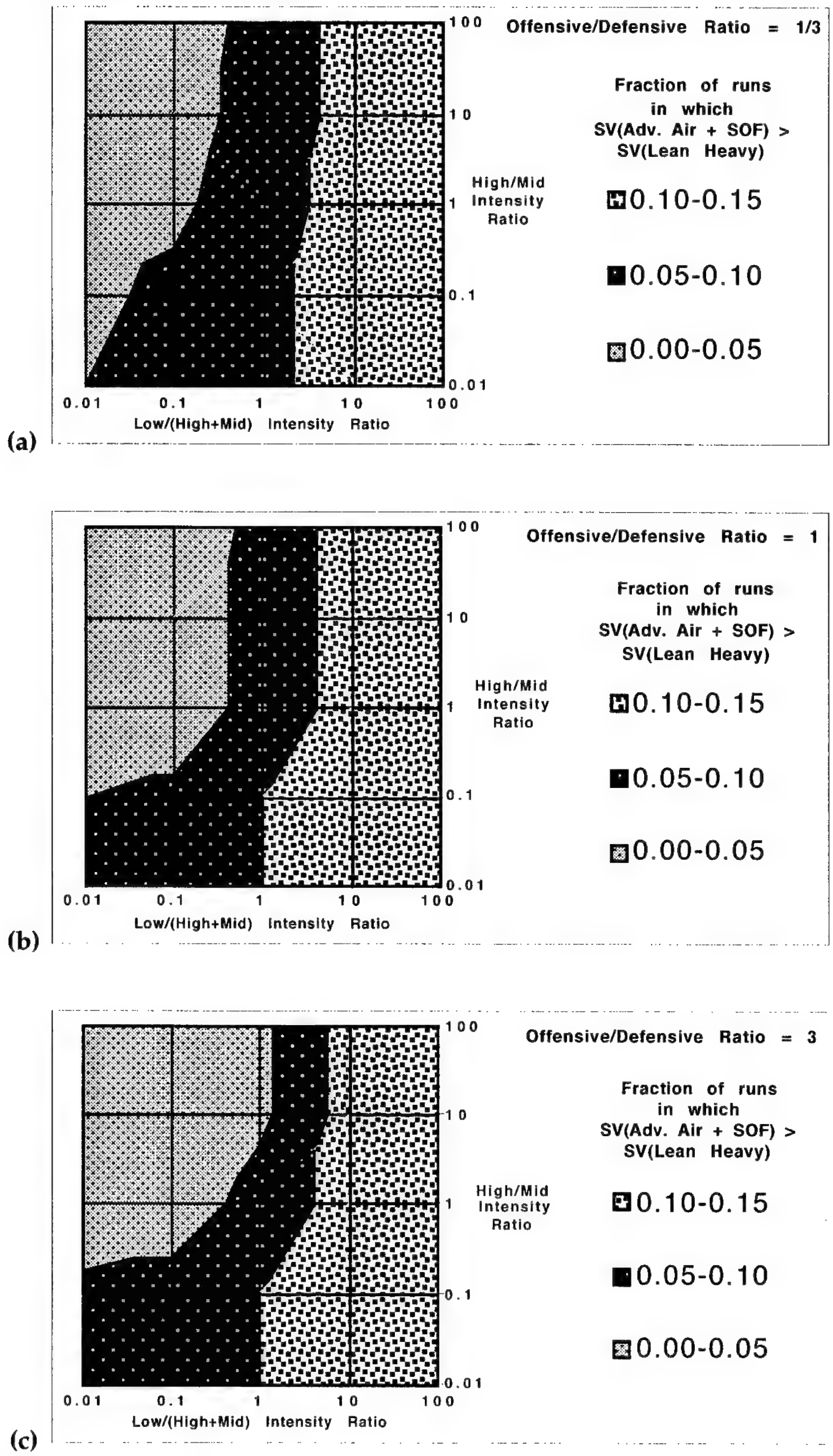



**Figure 9.4. Strategic Value Preference Surface for Advanced Air + SOF over Lean Heavy in the Far Term when: (a) defensive missions are more important; (b) offensive and defensive missions are equally important; and (c) offensive missions are more important.**

## 9.3 SCENARIOS FOR FUTURE SECURITY ENVIRONMENTS

All of these preference surfaces have a similar shape: a peak or depression at the upper left corner of the third slice, where the high-intensity evict mission is the most important, and a gradual drop or rise towards the right in all three slices, where the two low-intensity missions, protect and stabilize, are given more weight. The evaluation model uses the same mission-based attribute weights for all options, in both time frames, so differences among options tend to be amplified or suppressed accordingly in the mission effectiveness values. The resulting similarities in the preference surfaces also create an opportunity to focus on a few interesting scenarios—specific locations in the parameter space that represent different types of future security environments. Each scenario can be interpreted as the ensemble of missions that U.S. forces will have to perform in the future, or as the mix of missions associated with a typical future conflict.

### Scenario Descriptions

To illustrate this approach, three scenarios are considered: (A) small-scale interventions, (B) balanced mix of contingencies, and (C) major regional conflicts. Following the convention for scenario analysis, this triplet consists of one modest baseline scenario (B), and two other more extreme scenarios (A and C) that move away from the baseline in opposite directions (Schwartz, 1991). The scenarios are each described briefly below, and Table 9.2 shows their parameter values and the corresponding strategic weights for each mission. Figure 9.5 depicts how the mission weights are distributed in each scenario, and points out their locations in parameter space on the near-term medium versus heavy preference surface.

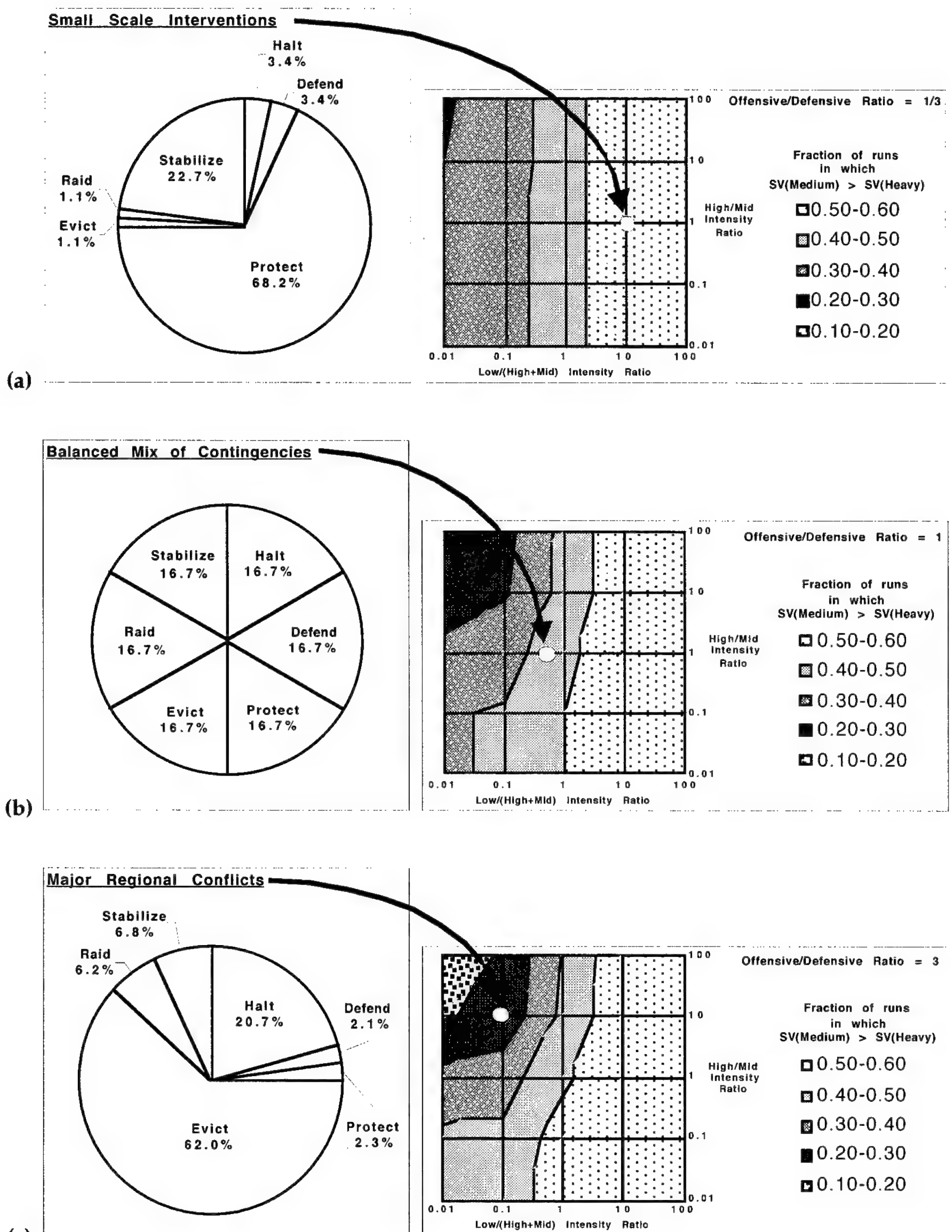



**Figure 9.5. Relative Importance of Missions in Three Future Scenarios: (a) Small-Scale Interventions; (b) Balanced Mix of Contingencies; and (c) Major Regional Conflicts. Scenario Locations are Indicated on Preference Surface for Medium over Heavy in the Near Term.**

**Table 9.2**

**Parameters and Strategic Weights for Future Security Environment Scenarios**

| Name of Input | Input Values for Future Scenarios: (A) Small-Scale Interventions | (B) Balanced Mix of Contingencies | (C) Major Regional Conflicts |
|---|---|---|---|
| *Parameters* | | | |
| Offensive/Defensive ($P_1$) | 1/3 | 1 | 3 |
| Low-/Non-Low-Intensity ($P_2$) | 10 | 1/2 | 1/10 |
| High-/Mid-Intensity ($P_3$) | 1 | 1 | 10 |
| *Strategic Weights* | | | |
| Halt | 0.0341 | 0.1667 | 0.2066 |
| Defend | 0.0341 | 0.1667 | 0.0207 |
| Protect | 0.6818 | 0.1667 | 0.0227 |
| Evict | 0.0114 | 0.1667 | 0.6198 |
| Raid | 0.0114 | 0.1667 | 0.0620 |
| Stabilize | 0.2273 | 0.1667 | 0.0682 |

(A) *Small-Scale Interventions.* This scenario represents a future where the U.S. has few major rivals, so the likelihood that it will have to engage in high-intensity, or even mid-intensity combat is fairly small. Instead, this scenario focuses on low-intensity missions, with a substantial tilt towards defense, rather than offense. There are still plenty of small-scale local and regional conflicts where the U.S. will find it necessary to intervene, usually against rogue states, to defend traditional national interests, prevent a widening of the conflict, or protect targeted civilians. These interventions are frequent, and involve early, aggressive action to mount a quick, effective defense. Standing policies to counter aggression in concert with major allies help minimize political obstacles to this type of rapid response. This scenario's emphasis on defense and low-intensity gives the protect mission over two thirds of all the mission weight. The offensive low-intensity mission, stabilize, receives almost 23 percent—a large portion of the remaining weight. The high-intensity and mid-intensity missions split what is left; on the defensive side, halt and defend receive about 3.4 percent each, and on the offensive side, evict and raid each receive just over 1 percent.

(B) *Balanced Mix of Contingencies.* In the future associated with this scenario, U.S. forces are expected to perform missions that span the full spectrum

of conflict, ranging from low-intensity peace keeping to high-intensity maneuver warfare. Regional adversaries with substantial capabilities pose a threat to U.S. interests in key parts of the world, while a variety of rogue states with varied capabilities periodically initiate conflicts, through aggression against their neighbors or internal minorities, where the U.S. is able and willing to intervene. This wide range of conflicts leads to a diverse and balanced mix of contingencies for U.S. forces in this future. Thus, equal emphasis is placed on offensive and defensive missions, and on missions at different levels of intensity, so all six missions receive an equal weight of 1/6.

(C) *Major Regional Conflicts*. This scenario represents a future that resembles the past. It envisions a situation reminiscent of the Cold War, where the U.S. is primarily concerned with its readiness for high-intensity warfare with a highly-capable adversary in a few key regions of the world. In this future, the emphasis is on offense rather than defense, and mid-intensity and low-intensity missions are not so important, since they are viewed primarily in terms of their supporting role in a major regional war. U.S. forces do not engage in small-scale interventions very often, since there are few rogue states left in the world, and the remaining ones are less dangerous and less active. Any peace keeping or enforcement operations that do arise are usually relegated to allied forces from the regions affected. The offensive focus of this scenario and its emphasis on high-intensity missions together give the evict mission over 60 percent of all the mission weight. Over 20 percent goes to the halt mission, the defensive counterpart of evict, while the other defensive missions, defend and protect, only receive just over 2 percent each. The offensive mid-intensity and low-intensity missions, raid and stabilize, fare a bit better, with between 6 and 7 percent of the total weight each.

## Near-Term Results

For each of these three scenarios, Table 9.3 shows the median strategic values of the near-term options, and Figure 9.6 shows a bar chart of these results

that includes the corresponding 90-percent confidence intervals. Since the strategic values are derived from the effectiveness results, it is not surprising that they exhibit the same pattern: heavy and medium vying for first, with small overlapping confidence intervals; air + SOF clearly in third place, with a large confidence interval that overlaps a bit with all the others; light in fourth, with a moderately sized interval; and air only in last place, with a very large interval that extends up to engulf light's.[71]

**Table 9.3**

**Median Strategic Value of Options in Future Security Environment Scenarios**

| Force Option | Median Strategic Value of Options in Future Scenarios | | |
|---|---|---|---|
| | (A) Small-Scale Interventions | (B) Balanced Mix of Contingencies | (C) Major Regional Conflicts |
| *Near Term* | | | |
| Heavy | 0.907 | 0.932 | 0.964 |
| Medium | 0.916 | 0.918 | 0.925 |
| Light | 0.534 | 0.550 | 0.604 |
| Air Only | 0.321 | 0.401 | 0.522 |
| Air + SOF | 0.745 | 0.759 | 0.796 |
| *Far Term* | | | |
| Lean Heavy | 0.777 | 0.809 | 0.850 |
| Future Medium | 0.973 | 0.980 | 0.989 |
| Enhanced Light | 0.693 | 0.683 | 0.677 |
| Advanced Air Only | 0.426 | 0.477 | 0.529 |
| Advanced Air + SOF | 0.730 | 0.735 | 0.742 |

The rank frequencies for the near-term options in each scenario are shown in Table 9.4. The medium option places first more often than the heavy option in scenario A, but heavy wins more often in scenario B, and especially in scenario C. The preference frequencies for this pair of options, which are shown in Table 9.5, confirm this trend; medium is only preferred over heavy 58 percent of the time in scenario A, 42 percent in scenario B, and just 23 percent in scenario C. The air + SOF option consistently places third well over 80 percent of the time in all three

--------

[71] Note that the median strategic values for all the options are a bit higher, and their confidence intervals are all a bit smaller, in scenario C relative to scenario B, and in B relative to

scenarios, and even manages several first or second place rankings. The light option places fourth more rankings than the air only option in all three scenarios, with its best performance in scenario A, and its worst in scenario C. The preference frequencies for this pair in Table 9.5 show that light is preferred to air only 86 percent of the time in scenario A, 79 percent in scenario B, and 69 percent in scenario C.

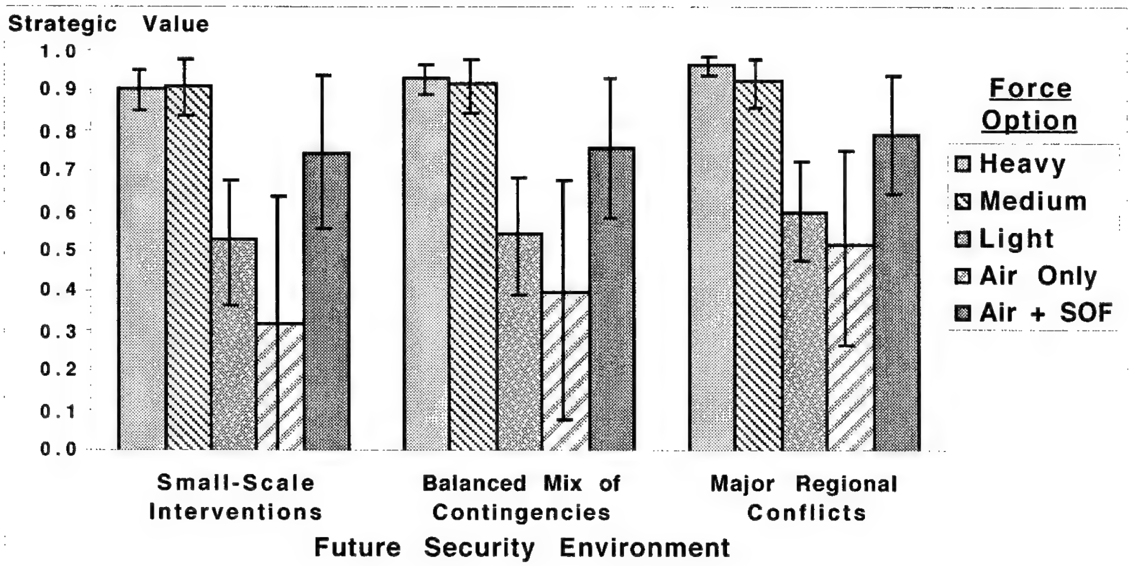



**Figure 9.6. Strategic Value of Near-Term Options in Future Security Environment Scenarios**

## Far-Term Results

The median strategic values of the far-term option are shown in Table 9.3 for each of the three scenario, and they are depicted in Figure 9.7 with their 90-percent confidence intervals. These results, of course, follow the same trends as the far-term effectiveness outcomes: the future medium option is a clear winner in every scenario, with lean heavy in second place, advanced air + SOF in third, enhanced light in fourth, and advanced air only in fifth. The rank frequencies of these options, which are shown in Table 9.4, confirm these observations, and

---

A. The reason for this trend is that the high-intensity missions have a lower effectiveness floor

indicate the significance of the overlaps in their confidence intervals. In scenario A, lean heavy's hold on second place is weakest, enhanced light is at its best, and advance air + SOF is pulled both ways, with its most second place rankings, but its least thirds. In scenario C, by contrast, lean heavy is unchallenged in second place, advanced air + SOF is secure in third place, and enhanced light is solidly in fourth, although air only is at its best with several non-last-place rankings. The preference frequencies for the two most interesting pairs of far-term options, advanced air only + SOF versus enhanced light and versus lean heavy, are shown in Table 9.5. These results confirm the preceding observations. In scenario A, advanced air + SOF does its best against lean heavy, winning 12 percent of the time, and its worst against enhanced light, losing 24 percent of the time. In scenario C, the situation is reversed; advanced air + SOF does its best versus enhanced light, winning 9 times out of 10, but loses to lean heavy every time. As expected, the results in scenario B fall somewhere in between: advanced air + SOF beats lean heavy only 6 percent of the time, and loses to enhanced light only 16 percent of the time.

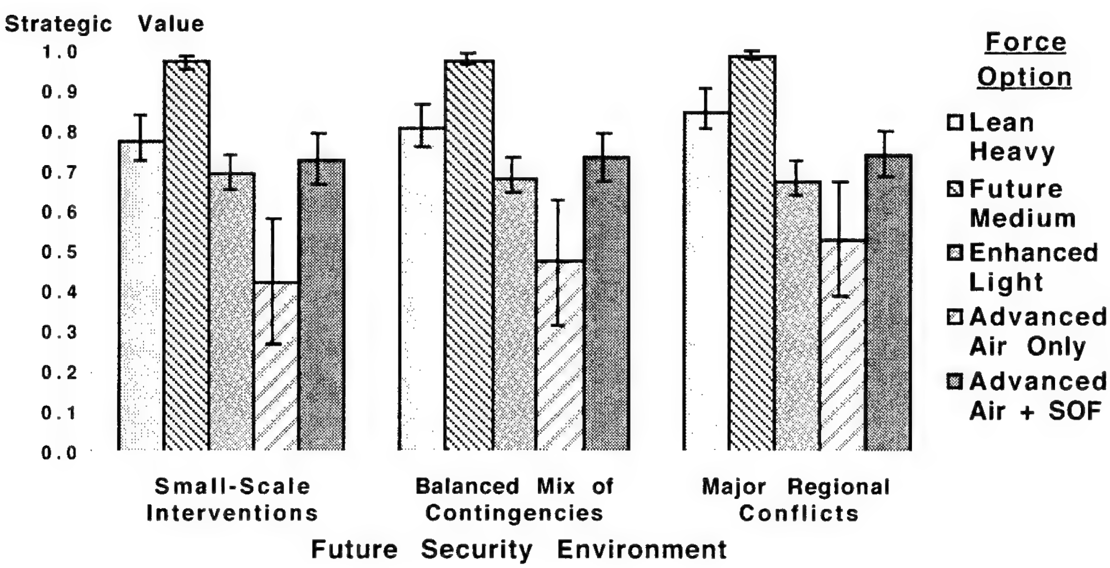



**Figure 9.7. Strategic Value of Far-Term Options in Future Security Environment Scenarios**

---

than the other missions, and are emphasized more in C than in B, and in B than in A.

## Table 9.4

### Rank Frequencies of Options in Future Security Environment Scenarios

| | Rank Frequency of Force Option for Each Mission | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | (A) Small-Scale Interventions | | | | | (B) Balanced Mix of Contingencies | | | | | (C) Major Regional Conflicts | | | | |
| **Force Option** | 1 | 2 | 3 | 4 | 5 | 1 | 2 | 3 | 4 | 5 | 1 | 2 | 3 | 4 | 5 |
| *Near Term* | | | | | | | | | | | | | | | |
| Heavy | 41 | 49 | 10 | 0 | 0 | 56 | 37 | 7 | 0 | 0 | 74 | 24 | 2 | 0 | 0 |
| Medium | 53 | 45 | 2 | 0 | 0 | 39 | 57 | 4 | 0 | 0 | 21 | 74 | 5 | 0 | 0 |
| Light | 0 | 0 | 3 | 83 | 14 | 0 | 0 | 3 | 76 | 21 | 0 | 0 | 3 | 66 | 31 |
| Air Only | 0 | 0 | 1 | 13 | 86 | 0 | 0 | 1 | 20 | 79 | 0 | 0 | 3 | 28 | 69 |
| Air + SOF | 6 | 6 | 84 | 4 | 0 | 5 | 6 | 85 | 4 | 0 | 5 | 2 | 87 | 6 | 0 |
| *Far Term* | | | | | | | | | | | | | | | |
| Lean Heavy | 0 | 87 | 9 | 4 | 0 | 0 | 94 | 6 | 0 | 0 | 0 | 100 | 0 | 0 | 0 |
| Future Medium | 100 | 0 | 0 | 0 | 0 | 100 | 0 | 0 | 0 | 0 | 100 | 0 | 0 | 0 | 0 |
| Enhanced Light | 0 | 1 | 27 | 72 | 0 | 0 | 0 | 16 | 81 | 3 | 0 | 0 | 10 | 82 | 8 |
| Advanced Air Only | 0 | 0 | 0 | 0 | 100 | 0 | 0 | 0 | 3 | 97 | 0 | 0 | 1 | 7 | 92 |
| Advanced Air + SOF | 0 | 12 | 64 | 24 | 0 | 0 | 6 | 78 | 16 | 0 | 0 | 0 | 89 | 11 | 0 |

NOTE: These are raw frequencies from a sample of 100 Monte Carlo runs.

## Table 9.5

### Preference Frequencies in Future Security Environment Scenarios

| **Option Pair, with Preference** | Preference Frequencies of Option Pairs in Future Scenarios | | |
|---|---|---|---|
| | (A) Small-Scale Interventions | (B) Balanced Mix of Contingencies | (C) Major Regional Conflicts |
| *Near Term* | | | |
| Medium vs. Heavy | 0.58 | 0.42 | 0.23 |
| Light vs. Air Only | 0.86 | 0.79 | 0.69 |
| *Far Term* | | | |
| Adv. Air + SOF vs. Enh. Lt. | 0.76 | 0.84 | 0.90 |
| Adv. Air + SOF vs. Lean Hvy. | 0.12 | 0.06 | 0.00 |

## Implications of Option Comparison Results

Taken as a whole, these results have some interesting implications. In the near term, a medium-weight force is only preferred over a traditional heavy armored force in a limited set of circumstances—futures that are dominated by small-scale interventions involving low-intensity combat and peace operations. Even in this sort of future, the medium-weight alternative is only slightly better, since the heavy option may outperform the medium option in many situations.

If the future requires more offensively oriented, high-intensity operations, then a traditional heavy armored force is clearly favored.

In the far term, however, a future medium-weight force built around a new combat system with substantial potency and protection is almost always superior to a leaner, modernized heavy armored force, across a full range of future security environments. If such a force is prohibitively expensive, then the lean, modernized heavy armored force is generally the second best choice, although in a future where small-scale interventions are the norm, an advanced air option, augmented by special operations teams, may be better in a limited set of situations. If this option is also too expensive, an enhanced light force would be the next best alternative, especially if the future is likely to be dominated by small-scale interventions.

## 9.4 CONCLUDING REMARKS

This chapter described the results of the prioritization phase, which screened all of the options to provide some initial insights, and then scored them based on strategic value. This calculation was parameterized, based on mission importance, to create a space in which surface plots were drawn, which showed how sensitive option preference were to strategic uncertainty. Chapter 10 describes the results of the fifth phase—exploration—in significant detail. Two types of exploration are considered in this phase: perturbation in the expert-based model inputs, and alterations in the composition of the force options under evaluation. The large perturbations highlight a key capability of the HIMAX process: examining implications of divergent minority opinions.

# 10. EXPLORATION

This phase of the HIMAX process involves two types of exploration. The first type, expert assessment perturbation, involves changing the ratings and other inputs that determine the parameters of the evaluation model. These perturbations affect how options are mapped to an effectiveness level for each mission—on an effectiveness terrain, of sorts—based on their composition and the characteristics of their components. In the second type of exploration, force option alteration, the composition of an option is changed, thereby moving it to a new location on the effectiveness terrain. The impact of each perturbation or alteration is observed to see how sensitive the results are to such a change.[72] While a large number of perturbations and alterations were considered, only the most interesting and influential are presented and discussed here.

## 10.1 EXPERT ASSESSMENT PERTURBATION

Perturbations can involve any of the model inputs, including the value functions assigned to each characteristic, and the various attribute, characteristic and system role ratings. The value function perturbations use alternative selections that had considerable support from the experts; most had as many votes as the assigned function, but lost a tiebreaker, and a few were a close second with multiple votes. The rating perturbations involve either large changes in controversial ratings, or small changes in influential ratings. The degree of disagreement among the experts identifies candidates for the controversial perturbations, while small systematic changes reveal the individual ratings that are the most influential so that they can be combined together.

--------

[72] Chapter 3 describes two measures of impact: the average rank shift sum (ARSS) and the average differential effect (ADE); the ARSS measures impact more directly, so it is used the most.

## Alternative Value Function Selections

Table 10.1 shows the alternative value function assignments considered, along with their impact on the option rankings in the near term and far term portions of the analysis. These assignment changes are specified by the characteristic involved, and the baseline and alternative selections, with the number of experts who chose those functions in parentheses. The assignments for multiple characteristics could be changed at the same time, but all of the changes considered here involve a single characteristic value function assignment. The first four changes switched the assignment to another value function that had just as many expert votes as the baseline assignment. The remaining alternative functions all had the second highest number of votes, and were always chosen by at least two of the experts.

**Table 10.1**

**Impact of Using Alternative Value Function Selections**

| Change in Characteristic Value Function Assignment | Average Rank Shifts Per Mission | |
|---|---|---|
| | Near Term | Far Term |
| Transportability: Convex/cave (2) → Convex (2) | 4.27 | 1.73 |
| Firepower: Linear (3) → Convex (3) | 6.40 | 4.87 |
| Protection: Linear (2) → Concave (2) | 4.63 | 3.03 |
| Protection: Linear (2) → Convex/cave (2) | 9.57 | 1.17 |
| Mobility: Concave (4) → Convex/cave (2) | 6.63 | 8.17 |
| Stealth: Convex (3) → Linear (2) | 9.23 | 4.27 |
| Self-sufficiency: Linear (5) → Convex (2) | 13.13 | 20.03 |
| Awareness: Convex/cave (5) → Concave (2) | 10.53 | 4.00 |
| Coordination: Convex/cave (4) → Concave (3) | 5.70 | 5.17 |
| Economy: Concave (3) → Convex/cave (2) | 6.40 | 2.27 |
| Ability to Support: Linear (3) → Convex (2) | 7.07 | 7.73 |
| Ability to Support: Linear (3) → Convex/cave (2) | 2.87 | 0.67 |

NOTE: The number of experts who chose the value function is shown in parentheses.

Of these twelve alternative selections, the two highlighted in Table 10.1 deserve closer attention. Among the four tied selections, using the convex/cave function for protection instead of the linear function had the most significant impact on the near-term option rankings, with an average of 10 rank shifts per mission. This change, however, had only a minimal effect on the far-term

rankings, and none of the other three tied selections had much of an impact either, since all of them caused an average of less than 5 rank shifts per mission. The most interesting of the remaining eight alternative assignments was the use of the convex function for self-sufficiency rather than the linear function. This change had the greatest impact of all the alternative selections considered, with an average of over 13 rank shifts per mission among the near-term options, and over 20 among the far-term options.

*Protection: Linear → Convex/cave*

In the near term, this alternative selection had the most impact on the rankings of the top two options, shifting the heavy option into first place more often, bumping the medium option down into second place. In every mission, except evict, where heavy already had a first-place frequency of almost 90 percent, these first-to-second-place shifts amounted to at least around 20 of the 100 runs. For example, in the stabilize mission, where heavy had the fewest first-place rankings using the linear function for protection, its first-place frequency increased from 39 to 60 percent when the convex/cave function was used for protection instead. The overall effect of this change is clear in the new preference surface for medium over heavy, which is shown in Figure 10.1, along with copies of the baseline plots for comparison. The shape of the new surface is similar to the baseline, but its elevation—the normalized preference frequency—is lower everywhere, never exceeding 0.4, and dropping to well below 0.1 if the evict mission is more important than any of the other missions. The impact on the scenario preference frequencies for this pair of options, which is shown in Table 10.2, reflects this over shift in favor of heavy. In scenario C, medium's preference frequency drops to only 0.05, and in scenario B, it falls to just 0.15. Even in scenario A, medium is now only preferred to heavy about a third of the time.

**Table 10.2**

**Preference Frequencies in Future Scenarios, with Alternative Value Functions**

| *Alternative Value Function* **Time Frame** **Option Pair** | **Preference Frequencies of Option Pairs in Future Scenarios** | | |
|---|---|---|---|
| | (A) Small-Scale Interventions | (B) Balanced Mix of Contingencies | (C) Major Regional Conflicts |
| *Protection:* *Linear → Convex/cave* Near Term Medium vs. Heavy | 0.58 → 0.32 | 0.42 → 0.15 | 0.23 → 0.05 |
| *Self-sufficiency:* *Linear → Convex* Near Term Medium vs. Heavy | 0.58 → 0.66 | 0.42 → 0.57 | 0.23 → 0.35 |
| Far Term Adv. Air + SOF vs. Lean Hvy | 0.12 → 0.79 | 0.06 → 0.52 | 0.00 → 0.12 |

*Self-sufficiency: Linear → Convex*

This alternative selection had a substantial impact on the option rankings in both the near term and the far term. In the near term, the largest rank shifts were for the air + SOF option. Its third-place frequency dropped as it moved up into second and first place more often. These shifts ranged from a low of less than 10 (of 100) for evict, to over 30 for stabilize, with shifts in the twenties for all of the other missions. Medium also made significant gains on heavy under this alternative, although its net increases in first place were limited because of the inroads made by air + SOF. In fact, both of these insurgent options placed first more often than heavy in the stabilize mission under this alternative; medium was first 57 percent of the time, air + SOF 24 percent, and heavy the remaining 19 percent. Medium also placed first most often in the protect and raid missions (53 percent in protect, and 49 percent in raid), but heavy still won most often in the other three missions (46 percent in halt, 55 percent in defend, and 75 percent in evict). Figure 10.2 shows the effect that this alternative had on the preference surface for these two options: the shape is very similar to that of the baseline surface, but the elevation is generally higher. The preference frequency exceeds 0.7 if stabilize is the most important mission, and dips below 0.4 only if evict is much more important than the other missions. The critical 0.5 threshold is now

well into the region where low-intensity missions are considerably less important than other missions. The corresponding scenario preference frequencies shown in Table 10.2 reinforce this: heavy is only preferred more often than medium in scenario C, where medium now wins over a third of the time, as compared to less than a quarter in the baseline case.

This alternative value function selection has a much more dramatic effect on the far-term option rankings. The lean heavy option, which dominates second place in the baseline case, experiences the largest rank shifts due to this change. It drops to third or even fourth place in about 70 of the 100 runs for the two low-intensity missions, but in only 3 runs for the evict mission, and in between 38 and 49 runs for the remaining three missions. The advanced air + SOF option shifts up to second place in most of these cases, although in the low-intensity missions the enhanced light option grabs 13 more second place spots, and places third more often as well—13 more times in protect, and 21 more in stabilize. As a result, in these two missions the advanced air + SOF option now places second about 70 percent of the time, while the enhanced light option makes good showings in both, winning second more often than lean heavy in stabilize, and only a few runs less often in the protect. Enhanced light is not a contender for second in the remaining missions, and lean heavy is still almost always in second place behind future medium in the evict mission. In the defend mission, lean heavy wins second about 60 percent of the time, and wins half of the time in the halt mission. Advanced air + SOF is only a couple of runs behind in halt, however, and wins half of the time in the raid mission, where lean heavy is several runs behind it thanks to a handful of second-place rankings by enhanced light. These very large rank shifts are readily apparent in the new preference surface for advanced air + SOF over lean heavy, which is shown in Figure 10.3. This surface rises much more steeply to the right, where low-intensity missions are more important, even exceeding 0.8 if offensive missions are as or more important than defensive ones. It is, however, still quite low in the upper right corner of the offensive slice, where the evict mission is very important. This

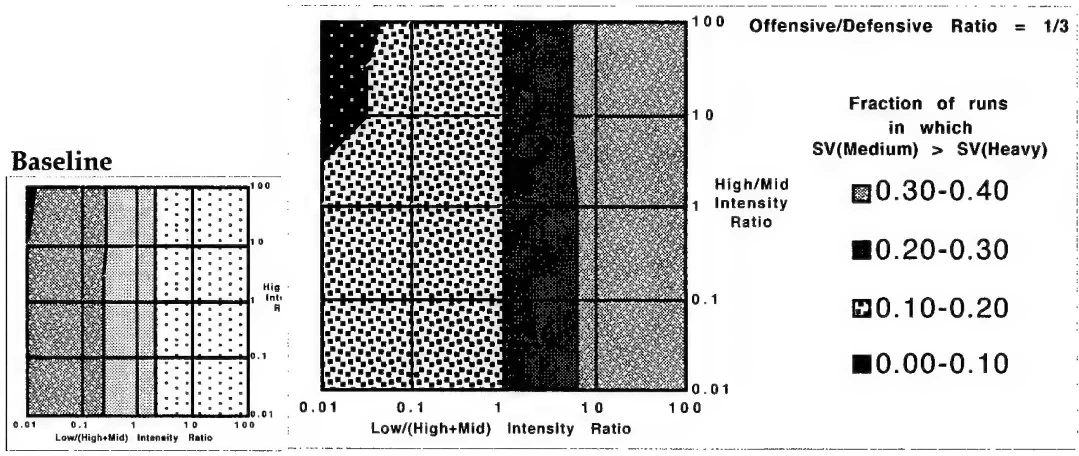
contrast is clear in the scenario preference frequencies for this pair of options, which are included in Table 10.2. Advanced air + SOF is only preferred to lean heavy 12 percent of the time in scenario C, which emphasized evict, but jumps up to over 50 percent in scenario B, where all missions are equally important, and to almost 80 percent in scenario A, which focuses on low-intensity missions.

### Attribute Rating Changes

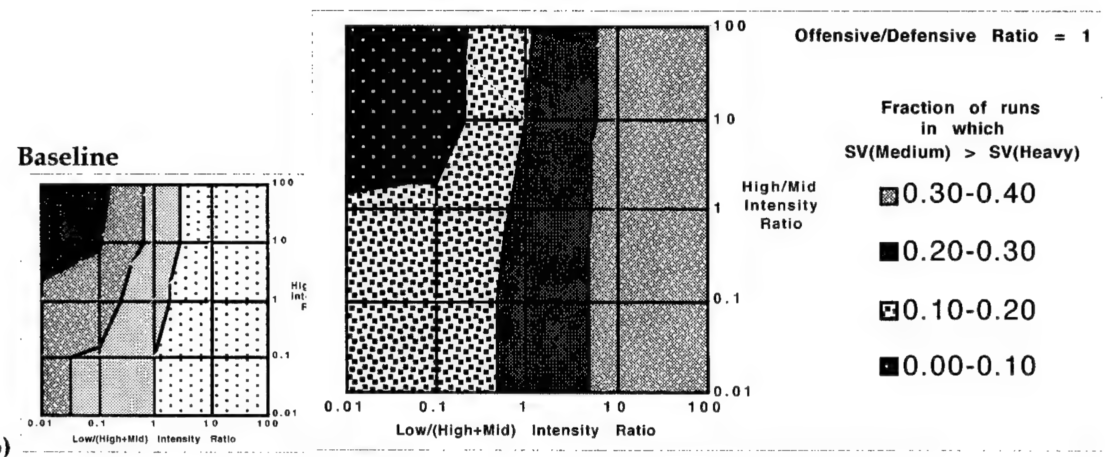
The attribute ratings indicate how important the attributes are relative to one another, and determine the attribute weights used in the evaluation model for each mission. The value of each input rating is based on the corresponding pair-wise assessments made by the experts—the middle response in each case—and the same ratings are used in both time frames. (It is assumed that the relationships among the attributes will remain the same over time, so the experts only provide a single set of assessments for both time frames.) The attribute input ratings were subjected to two types of perturbations: large, controversial changes and combinations of small, influential changes. Many perturbations of both types were evaluated, but only those that met certain selection criteria, and had the greatest impact or the most interesting effects, are discussed here.

#### *Large, Controversial Perturbations*

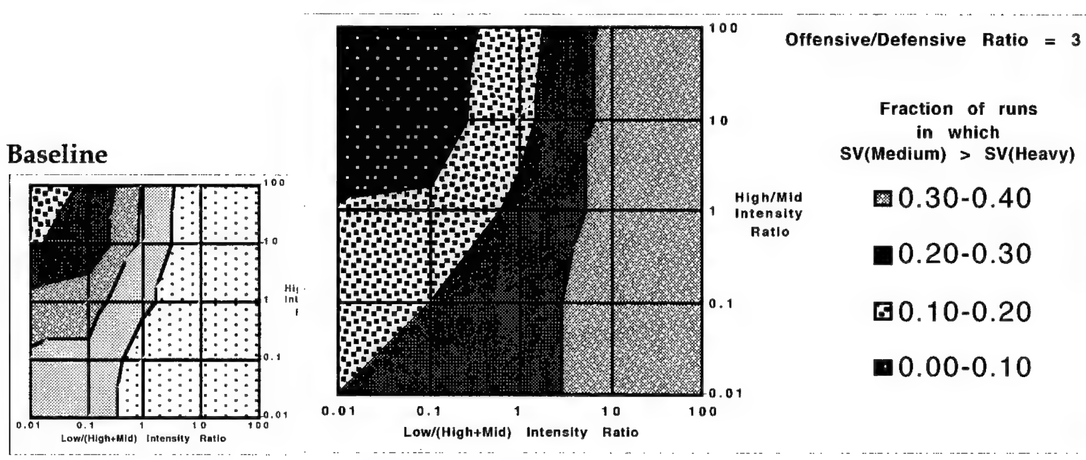
A large change in an attribute rating is controversial because it indicates that at least one expert gave a response substantially different from the baseline value used in the analysis. For each attribute rating, the differences between the highest and lowest responses and the middle baseline value were calculated in terms of scale intervals (e.g., the difference between 3 and 1/5 is 6 intervals; 2 from 3 to 1, and 4 from 1 to 1/5). Only deviations of 4 or more intervals were considered large enough to be controversial, and in missions where there were many controversial ratings the threshold for consideration was raised to 5 or 6. The effects of these large, controversial rating changes were compared on their own, and in a number of relevant combinations.



(a)



(b)



(c)

**Figure 10.1. Preference Surface for Medium over Heavy in Near Term if Protection Scale Is Convex/cave, when: (a) defensive missions are more important; (b) offensive and defensive are missions equally important; and (c) offensive missions are more important.**

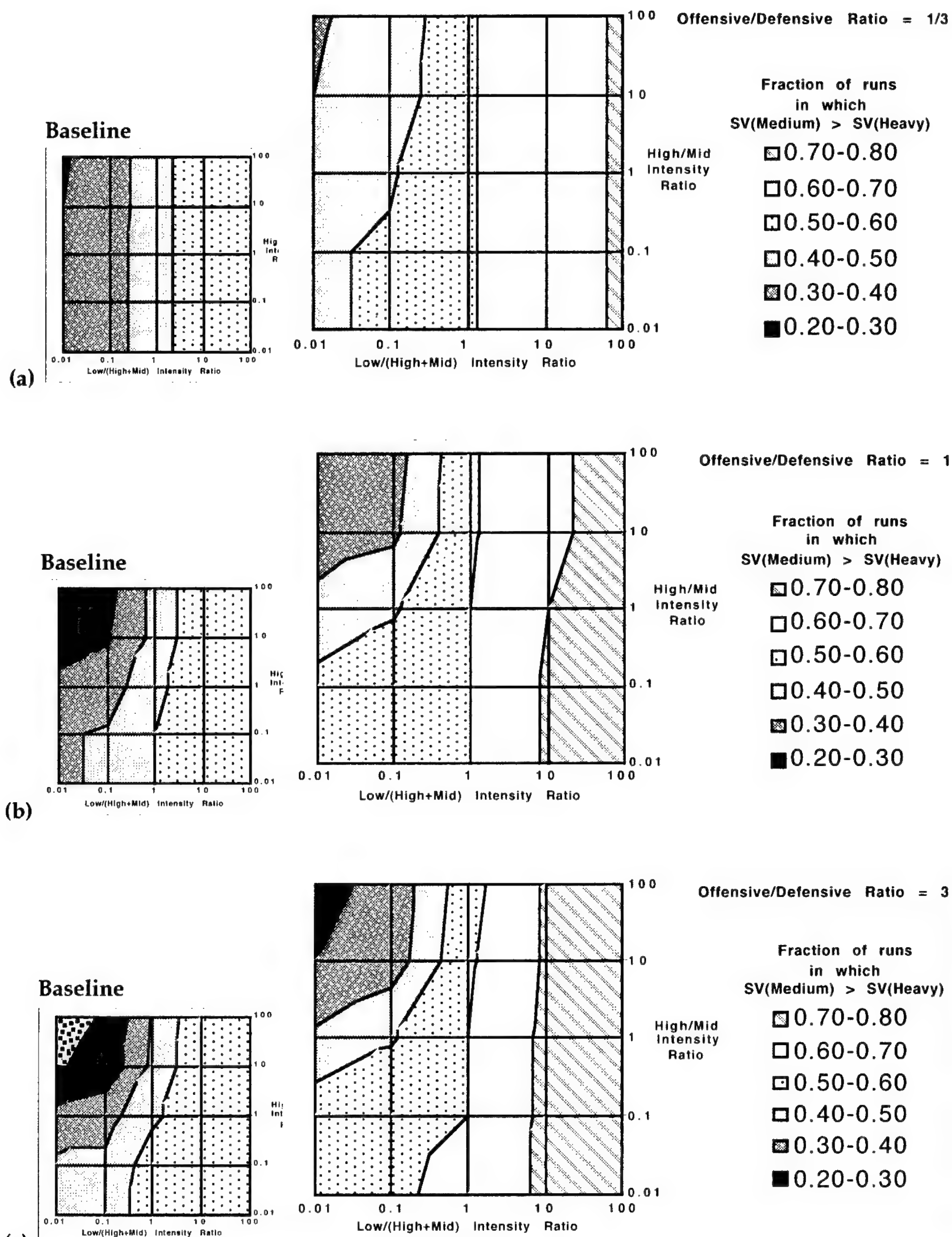



**Figure 10.2. Preference Surface for Medium over Heavy in Near Term if Self-sufficiency Scale Is Convex, when: (a) defensive missions are more important; (b) offensive and defensive are missions equally important; and (c) offensive missions are more important.**

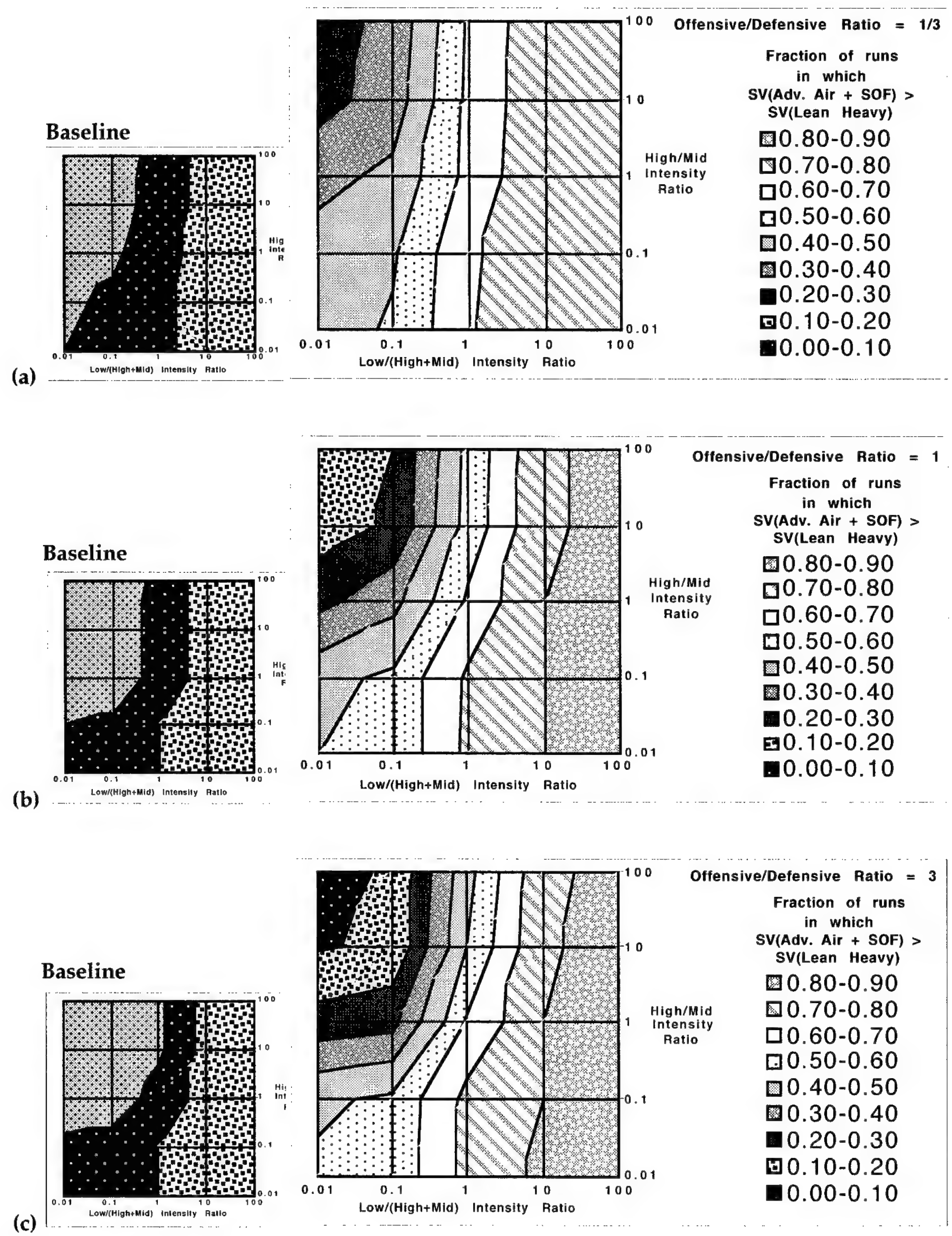



**Figure 10.3. Preference Surface for Advanced Air + SOF over Lean Heavy in Far Term if Self-sufficiency Scale Is Convex, when: (a) defensive missions are more important; (b) offensive and defensive are missions equally important; and (c) offensive missions are more important.**

Table 10.3 describes the most interesting pairs of large, controversial changes within each mission, and shows the impact they had, both individually and in combination, on the option rankings. The impact of these pairs was high relative to the other perturbations evaluated for the same mission, and met two additional criteria: both involved the same attribute, and were based on the responses of the same expert(s).[73] These conditions ensure that the perturbation is plausible, since it is based on the opinion of an individual expert regarding the importance of a particular attribute. The perturbation selected for each mission is described and discussed below.

*HALT*. The most interesting of the large, controversial perturbations for the halt mission shifted the ratings of ability to shock relative to maneuverability and sustainability down from moderately more to strongly less important (3 → 1/5). In both the near and the far term, the change in the sustainability rating had much more impact than the maneuverability rating change, accounting for all or most of the impact when the two were combined. The magnitude of this impact was fairly modest, however, only averaging about 8 rank shifts (of the 100 runs) in the near term, and less than 5 in the far term. The medium option displaced the heavy option from first place most often in the near term (13 times), while the enhanced light option made the most gains in the far term (9 times), largely at the expense of the advanced air + SOF option. This result implies that placing more emphasis on sustainability and less on ability to shock in a halt-type mission would bring a medium-weight force nearly even with a traditional heavy armored force. While an enhanced light-weight force would also fare better in the far term under this change, its gains would not be sufficient to alter the prevailing option preferences for this mission; it would remain entrenched in fourth place.

--------

[73] Groups of three or more large changes rarely met both of these criteria, and often had only slightly more impact on the option rankings than the most influential pair they included, and sometimes even had less impact.

**Table 10.3**

**Impact of Selected Large, Controversial Attribute Rating Perturbations**

| *MISSION* Changes in Attribute Importance Ratings | Average Number of Rank Shifts | |
|---|---|---|
| | Near Term | Far Term |
| *HALT* | | |
| Maneuverability – Ability to Shock: 1/3 → 5 | 1.4 | 0.6 |
| Ability to Shock – Sustainability: 3 → 1/5 | 7.0 | 4.4 |
| Maneuverability – Ability to Shock: 1/3 → 5<br>Ability to Shock – Sustainability: 3 → 1/5 | 7.8 | 4.4 |
| *DEFEND* | | |
| Deployability – Ability to Shock: 1/3 → 7 | 8.8 | 8.2 |
| Deployability – Survivability: 1/2 → 7 | 9.4 | 7.4 |
| Deployability – Ability to Shock: 1/3 → 7<br>Deployability – Survivability: 1/2 → 7 | 19.8 | 29.4 |
| *PROTECT* | | |
| Deployability – Ability to Shock: 1 → 7 | 4.0 | 12.8 |
| Deployability – Survivability: 1 → 7 | 5.8 | 14.8 |
| Deployability – Ability to Shock: 1 → 7<br>Deployability – Survivability: 1 → 7 | 11.6 | 30.6 |
| *EVICT* | | |
| Deployability – Lethality: 1/8 → 3 | 5.0 | 2.2 |
| Deployability – Ability to Shock: 1/7 → 3 | 3.0 | 2.0 |
| Deployability – Lethality: 1/8 → 3<br>Deployability – Ability to Shock: 1/7 → 3 | 10.6 | 3.8 |
| *RAID* | | |
| Deployability – Lethality: 3 → 1/5 | 9.8 | 4.4 |
| Deployability – Ability to Shock: 1 → 1/6 | 8.4 | 3.4 |
| Deployability – Lethality: 3 → 1/5<br>Deployability – Ability to Shock: 1 → 1/6 | 15.0 | 5.8 |
| *STABILIZE* | | |
| Deployability – Ability to Shock: 1/2 → 7 | 7.0 | 13.6 |
| Deployability – Sustainability: 1 → 7 | 1.2 | 3.6 |
| Deployability – Ability to Shock: 1/2 → 7<br>Deployability – Sustainability: 1 → 7 | 8.2 | 21.0 |

*DEFEND.* A large increase in the importance of deployability in the defend mission relative to both ability to shock and survivability—from weakly or moderately less to very strongly more important (1/2, 1/3 → 7)—had a large impact in both time frames: an average of almost 20 rank shifts in the near term, and almost 30 in the far term. Individually, these two changes resulted in between 7 and 10 rank shifts in both time frames, so combining them increased their overall effect, especially in the far term. In the near term, the combined

perturbation resulted in a shift of over 30 rankings in favor of medium over heavy, more than doubling medium's first place frequency from less than 30 to over 60 of the 100 runs. In the far term, the impact on lean heavy was even more dramatic; it lost over 60 rankings to advanced air + SOF and, to a lesser extent, enhanced light, sinking from a near lock on second place to only winning this spot in just 36 of the 100 runs, with advanced air + SOF taking over the lead for second, winning 45 runs. Thus, if getting the force to a conflict sooner and more easily is a bit more important than its ability to shock and survive once there, then in the near term a medium-weight option is as good as, or even preferred to, a heavy armored force under most circumstances. And, in the far term, where an FCS-based force is always the superior option, advanced SOF teams or even improved light forces, in combination with advanced tactical aircraft, are favored over a leaner heavy force in most situations.

*PROTECT*. The most interesting change in the attribute ratings for protect is an increase in the importance of deployability relative to both ability to shock and survivability from equally to very strongly more important (1 → 7). This perturbation is almost the same as the one examined above for defend, and is in fact based on the responses of the same expert. The average impact was a bit less in the near term, over 11 rank shifts, and about the same in the far term, at over 30. The largest number of shifts in the near term again occurred between the medium and heavy options, with medium's first place frequency increasing from a bit over half of the runs to over 70 percent. Also, lean heavy was again toppled from second place in about 70 runs, dropping down to a total of only 16. Advanced air + SOF picked up most of these, increasing its total to exactly 50, while enhanced light also improved greatly, winning the remaining 34 second-place spots. Enhanced light also gained enough thirds to finish ahead of lean heavy, which ended up with almost 60 percent of the fourth place finishes. These results indicate that, if the expert who made these ratings is correct, and deployability is in fact much more important in the protect mission than the baseline consensus ratings imply, then a medium-weight force is clearly the

preferred option for this mission in the near term, and a SOF-augmented air option is the preferred second-best option in the far term.

*EVICT.* The perturbation shown for this mission increases the importance of deployability relative to lethality and ability to shock from very strongly less to moderately more important (1/7, 1/8 → 3). This pair of rating changes, which is based on the responses of the same expert as the halt perturbation discussed above, had a significant impact in the near term, but very little impact in the far term. In the near term there were an average of over 10 rank shifts, with 16 from heavy to medium, while in the far term there were fewer than 4 shifts on average, with 5 to 7 from advanced air + SOF to enhanced light. This fairly drastic increase in the relative importance of deployability did not have much impact in the far term, and had only a modest impact in the far term, with no effect on the prevailing option preferences.

*RAID.* The perturbation highlighted here for the raid mission involves the same two ratings as the one discussed above for the evict mission. In this case, however, the importance of deployability relative to lethality and ability to shock is reduced, rather than increased, from moderately more to strongly less important (3 → 1/5) for lethality, and from equally to much strongly less important (1 → 1/6) for ability to shock. This pair of alternative ratings was selected by two of the eight experts and, like its evict counterpart, it did not have much impact on the far-term option rankings, but did have a fairly large impact in the near term. In fact, the individual rating changes each had a sizeable impact on their own in the near term, causing an average of 8 to 10 rank shifts separately, and 15 in combination. Unlike the perturbations discussed for the other missions, however, these changes lowered the importance of deployability; the resulting 23 shifts between medium and heavy favored heavy, moving it from a slim majority with only about half of the first place spots to a clear advantage with almost three quarters. But, in the far term, the combined

perturbation only caused an average of about 6 rank shifts, with lean heavy gaining the 7 additional second place spots it needed to win all 100.

*STABILIZE.* Like all of the other large, controversial perturbations featured so far, the one selected for this mission changes the importance of deployability relative to ability to shock and one of the other four attributes—sustainability in this case. These two changes both increase the rating of deployability from equally or slightly less important to strongly more important (1/2, 1 → 7), relative to the other attribute. In both time frames, the change involving ability to shock had a much larger impact on its own than the sustainability change did; 7 rank shifts on average versus just 1 in the near term, and almost 14 versus less than 4 in the far term. The combined perturbation had a modest impact in the near term, causing an average of a little over 8 shifts in the near term, with about 15 going from heavy to medium, increasing its first place frequency from 55 to about 70, and strengthening its preeminence in the stabilize mission. In the far term, this pair of changes together resulted in an average of 21 rank shifts, with a drop of about 50 in the second-place frequency of lean heavy, from just over 80 down to about 30. Moreover, advanced air + SOF now placed second most often, in 45 of the 100 runs, and enhanced light placed second about a quarter of the time, and placed third about a third of the time. These gains spread out lean heavy's rank distribution to roughly one third each in second, third and fourth places.

The pairs of large, controversial changes selected for defend and protect are highlighted with shaded cells in Table 10.3 to indicate that their effects on the scenario preference frequencies in each time frame are discussed below. Several interesting combinations of the most influential small attribute changes are shown in Table 10.4, along with their impact on option rankings in the near and far term. Some of these perturbations are shaded as well because their scenario preference frequency effects are also examined later.

*Small, Influential Perturbations*

The impact of every possible ±1 change in the attribute ratings for each mission was calculated to determine which are the most influential. Since these changes are small, they only have a limited impact on option rankings when applied individually. So, the changes that had the largest impact on their own were combined together in perturbations that shifted the importance of the same attribute in the same direction. These combined perturbations represent small, systematic errors in the consensus opinion of the experts; for example, the experts may have slightly underestimated the importance of lethality relative to survivability, maneuverability and ability to shock in the evict mission. Such combinations of small aligned misjudgments can add up to have a substantial effect on the attribute weights for a mission, which can in turn affect the overall option rankings.

Table 10.4 shows six combined perturbations of this type, each of which involve small aligned shifts in four ratings. One perturbation was selected for the halt, defend, raid and stabilize missions, while two that shift the same ratings in opposite directions were selected for the protect mission. No perturbation is shown for the evict mission because even the most influential candidates did not have a sufficiently large impact to warrant a closer examination. Interestingly, these combinations all involve shifts in the importance a projection attribute (deployability or sustainability) relative to the four dominance attributes (lethality, maneuverability, ability to shock, and survivability). The impact these perturbations had on options rankings in the near and far term are shown in Table 10.4, and are discussed below for each mission.

*HALT*. The most influential combination of small rating changes for the halt mission increased the importance of deployability relative to each of the four dominance attributes from equally to weakly more important (1 → 2). This perturbation had about the same impact in both time frames, causing an average of about 11 rank shifts. In the near term, there were just less than 20 shifts from

heavy to medium, enough to give medium a slim majority of the first place spots. In the far term, lean heavy lost over 20 second place spots, mostly to advanced air + SOF, which still left it with over 70 of 100, since it placed second 93 times in the baseline case. These results imply that a small, but broad increase in the importance of deployability versus fighting capabilities would give a medium-weight force a slight edge over a heavy armored force for near-term halt-type missions. In the far term, however, such a change in emphasis would still leave a leaner modernized heavy force as the clear second-best choice for halt missions, behind a new FCS-based medium force, although an advanced air option, assisted by SOF teams, might be a bit better under certain circumstances.

*DEFEND.* The combination of multiple small rating changes highlighted here for the defend mission decrease the importance of the four dominance attributes in comparison to sustainability, from slightly more to equally important (2 → 1) for lethality and survivability, and from equally to slightly less important (1 → 1/2) for maneuverability and ability to shock. The net effect is to increase the weight placed on sustainability at the expense of the other attributes (except for deployability). In the near term, this perturbation led to an average of more than 9 rank shifts, with 14 going from heavy to medium, leaving heavy in first place just over half of the time, as compared to two thirds in the baseline. The impact in the far term was fairly small; there was an average of less than eight rank shifts, with just 7 going from lean heavy to advanced air + SOF in second place, and enhanced light gaining 12 third place spots. This perturbation tends to weaken the dominance of heavy armored forces for these types of missions, but still leaves them favored over medium-weight forces in most situations, and in the far term the leaner future version of these forces are still almost always the second best option.

**Table 10.4**

**Impact of Selected Multiple, Small Attribute Rating Perturbations**

| *MISSION* Changes in Attribute Importance Ratings | Average Number of Rank Shifts | |
|---|---|---|
| | Near Term | Far Term |
| *HALT* | | |
| Deployability – Lethality: 1 → 2 (+)<br>Deployability – Maneuverability: 1 → 2 (+)<br>Deployability – Ability to Shock: 1 → 2 (+)<br>Deployability – Survivability: 1 → 2 (+) | 10.8 | 11.6 |
| *DEFEND* | | |
| Lethality – Sustainability: 2 → 1 (–)<br>Maneuverability – Sustainability: 1 → 1/2 (–)<br>Ability to Shock – Sustainability: 1 → 1/2 (–)<br>Survivability – Sustainability: 2 → 1 (–) | 9.4 | 7.8 |
| *PROTECT* | | |
| Deployability – Lethality: 1 → 2 (+)<br>Deployability – Maneuverability: 2 → 3 (+)<br>Deployability – Ability to Shock: 1 → 2 (+)<br>Deployability – Survivability: 1 → 2 (+) | 7.8 | 20.0 |
| Deployability – Lethality: 1 → 1/2 (–)<br>Deployability – Maneuverability: 2 → 1 (–)<br>Deployability – Ability to Shock: 1 → 1/2 (–)<br>Deployability – Survivability: 1 → 1/2 (–) | 9.4 | 7.2 |
| *RAID* | | |
| Deployability – Lethality: 3 → 4 (+)<br>Deployability – Maneuverability: 1 → 2 (+)<br>Deployability – Ability to Shock: 1 → 2 (+)<br>Deployability – Survivability: 1 → 2 (+) | 8.6 | 12.2 |
| *STABILIZE* | | |
| Lethality – Sustainability: 1/3 → 1/4 (–)<br>Maneuverability – Sustainability: 1 → 1/2 (–)<br>Ability to Shock – Sustainability: 1/3 → 1/4 (–)<br>Survivability – Sustainability: 1 → 1/2 (–) | 7.4 | 12.6 |

*PROTECT*. The two perturbations considered for this mission change the importance of deployability relative to the four dominance attributes. The first perturbation increases the deployability ratings from equally to slightly more important (1 → 2) for most of the attributes, and from slightly to moderately more important (2 → 3) for maneuverability. This set of changes has a modest but significant impact in the near term: there are an average of almost 8 rank shifts, with medium gaining about 15 first place spots from heavy, moving it up from winning just over half of the time to winning fully two thirds of the runs.

This increase in the importance of deployability has a more dramatic impact on the option rankings in the far term: lean heavy loses about 50 second place spots, dropping to a total of about 35, while advanced air + SOF gains around 30 to win a plurality with 45 of the 100 runs (enhanced light wins second the other 20 percent of the time). In the second perturbation, the ratings of deployability are shifted in the opposite direction, going down to equally important (2 → 1) for maneuverability, and slightly less important (1 → 1/2) for the other attributes. In the near term, this causes an average of over 9 rank shifts, with about 15 from medium to heavy to give it a modest majority of the first place spots. This change has only a modest impact in the far term: an average of just over 7 rank shifts, with advanced air + SOF loosing about 10 second place spots to lean heavy, and gaining almost as many third place spots from enhanced light. The overall implications of these results are clear. Increasing the importance of deployability for a protect-type mission would make a medium-weight force the clear favorite in the near term, and would greatly increase the attractiveness of a SOF-augmented air option in the far term. Making deployability less important, however, would give a heavy armored force the advantage over a medium-weight force in the near term, and lock in an improved heavy force as the second-best choice for such missions in the far term.

*RAID.* The combination of small changes considered here for raid increase the importance of deployability relative to the four dominance attributes. These ratings increase from moderately to not quite strongly more important (3 → 4) for lethality, and from equally to slightly more important (1 → 2) for the other three attributes. In the near term, this perturbation led to an average of over 8 rank shifts, with more than 10 first-place rankings moving from heavy to medium, enough for medium to win almost 60 percent of the time, as compared to less than 50 percent in the baseline case. The impact in the far term was larger, but less significant: there were an average of about 12 rank shifts, and lean heavy placed second in more than 20 fewer runs, but still won this spot about 70

percent of the time, with advanced air + SOF now placing second about a quarter of the time. Increasing the importance of deployability in raid-type missions gives medium the boost it needs to pull ahead of heavy as the preferred option for such missions in the near term. In the far term this change only puts a modest dent in the lock an improved heavy armored force has on second-best by making advanced air + SOF as good or better a substantial fraction of the time.

*STABILIZE.* The combination small rating changes selected for the stabilize mission together increase the importance of sustainability relative to the four dominance attributes. The ratings for lethality and ability to shock relative to sustainability are reduced from moderately less to not quite strongly less important (1/3 → 1/4), while the same ratings for maneuverability and survivability are reduced from equally to weakly less important (1 → 1/2). The effects of this perturbation in the near term were modest: an average of over 7 rank shifts, with an increase in medium's first-place frequency from 55 to almost 70 percent. Its impact in the far term was a bit more interesting, but also did not change the prevailing preferences. The second-place frequency of lean heavy was lowered by about 30 of the 100 runs to a total of just over 50, while enhanced light picked up enough of these spots to finish with about a quarter of the total, leaving advanced air + SOF with only about a fifth. Thus, increasing the importance of sustainability in missions that focus on stabilization would make medium-weight forces even more attractive for such missions in the near term. In the far term, this change would make improved light or SOF with air options more appealing than modernized heavy forces under some circumstances.

*Impact of Selected Perturbations on Option Preferences*

The four attribute rating perturbations highlighted for each time frame in Tables 10.3 and 10.4 were selected for closer examination because they had the greatest overall impact on option preferences. The same two large, controversial perturbations were selected for both time frames; both involve large increases in the importance of deployability relative to ability to shock and survivability, the

first in the defend mission and the second in the protect mission. By contrast, two different combinations of small, influential changes were selected for each time frame, since, as Table 10.4 indicates, the perturbations of this type that had the most impact were different in the near and far term. The two top near-term perturbations involve small changes in the attribute ratings that increase the importance of deployabality in the halt mission and decreases it in the protect mission. The first of the two selected far-term perturbations increases the importance of deployability in the halt mission, while the second one increases the importance of sustainability in the stabilize mission.

**Table 10.5**

**Scenario Preference Frequencies for Medium Versus Heavy in the Near Term, Under Selected Attribute Rating Perturbations**

| **MISSION** **Attribute Rating Perturbation** | **Preference Frequencies in Future Scenarios** (A) Small-Scale Interventions | (B) Balanced Mix of Contingencies | (C) Major Regional Conflicts |
|---|---|---|---|
| DEFEND <u>Large increase</u> in importance of Deployability relative to Ability to Shock and Survivability | 0.58 → 0.58 | 0.42 → 0.51 | 0.23 → 0.24 |
| PROTECT <u>Large increase</u> in importance of Deployability relative to Ability to Shock and Survivability | 0.58 → 0.75 | 0.42 → 0.48 | 0.23 → 0.24 |
| HALT <u>Small increase</u> in importance of Deployability relative to Lethality, Maneuverability, Ability to Shock, and Survivability | 0.58 → 0.58 | 0.42 → 0.43 | 0.23 → 0.27 |
| PROTECT <u>Small decrease</u> in importance of Deployability relative to Lethality, Maneuverability, Ability to Shock, and Survivability | 0.58 → 0.45 | 0.42 → 0.40 | 0.23 → 0.23 |

To explore the implications of these perturbations, the effects they have on strategic-value-based preference frequencies are compared across three different futures. The same option pairs used for each time frame in the baseline analysis —medium versus heavy in the near term, and advanced air + SOF versus lean

heavy in the far term—are also considered here. Table 10.5 shows how the near-term perturbations shift preference frequencies in the three scenarios described in the preceding Section (Prioritization), which represent very different future security environments: (A) small-scale interventions, (B) balanced mix of contingencies, and (C) major regional conflicts. A similar comparison is shown in Table 10.6 for the far-term perturbations, and in both tables, each perturbation is described qualitatively, rather than in terms of the exact rating changes involved.

The results of the four near-term perturbations are quite interesting. Before discussing them specifically, however, it is important to point out that these attribute rating changes can only change the effectiveness results for one mission. So, if a perturbation changes the ratings for a mission that is weighted highly in a particular scenario, then it will have more impact on the preference frequencies in this scenario than in another where this mission receives less weight. This effect is evident in the preference frequency shifts caused by the first near-term perturbation, which involves the defend mission. This mid-intensity mission receives more weight in scenario B, which assigns equal weight to every mission, than in scenarios A or C, which focus on low and high intensity missions, respectively. Thus, it is not surprising that this perturbation had little if any effect in scenarios A and C, while increasing the preference frequency for medium over heavy from 0.42 to 0.51 in scenario B. The second perturbation, which affected the same ratings in the protect mission, only had a large impact in scenario A, where protect is by far the most important mission, raising the preference frequency up to 0.75 in favor of medium. The first of the small near-term perturbations involves the high-intensity halt mission, so it should have had the most effect on scenario C, which emphasizes high-intensity missions. Indeed, this perturbation did have its largest effect in scenario C, but the impact was minimal. The second of the small perturbations, which makes deployability less important in the protect mission, had a more substantial impact; it lowered the preference frequency for medium over heavy to 0.45 in scenario A.

## Table 10.6

### Scenario Preference Frequencies for Advanced Air + SOF Versus Lean Heavy in the Far Term, Under Selected Attribute Rating Perturbations

| **MISSION** **Attribute Rating Perturbation** | **Preference Frequencies in Future Scenarios** (A) Small-Scale Interventions | (B) Balanced Mix of Contingencies | (C) Major Regional Conflicts |
|---|---|---|---|
| DEFEND <u>Large increase</u> in importance of Deployability relative to: Ability to Shock, Survivability | 0.12 → 0.13 | 0.06 → 0.10 | 0.00 → 0.00 |
| PROTECT <u>Large increase</u> in importance of Deployability relative to Ability to Shock and Survivability | 0.12 → 0.52 | 0.06 → 0.08 | 0.00 → 0.00 |
| PROTECT <u>Small increase</u> in importance of Deployability relative to Lethality, Maneuverability, Ability to Shock, and Survivability | 0.12 → 0.34 | 0.06 → 0.07 | 0.00 → 0.00 |
| STABILIZE <u>Small increase</u> in importance of Sustainability relative to Lethality, Maneuverability, Ability to Shock, and Survivability | 0.12 → 0.15 | 0.06 → 0.07 | 0.00 → 0.00 |

The impact of the far-term attribute perturbations on the corresponding preference frequencies are also quite informative. It is important to note here that the baseline preference frequencies for advanced air + SOF over lean heavy are generally very low, ranging from zero in scenario C to just 0.12 in scenario A. All four of the selected perturbations shifted these frequencies up to some degree in scenarios A and B, but had no effect in scenario C. The first large perturbation had the most impact in scenario B, since it involves the mid-intensity defend mission, but only moved up the preference frequency of advanced air + SOF over heavy up to 0.10, and had almost no effect in scenario A. The second large perturbation, however, had a very substantial impact in scenario A, making advanced air + SOF more attractive than lean heavy a slim majority of the time, although it had very little effect in scenario B. The reason for this focused effect is that this perturbation involves the protect mission, which is by far the most important mission in scenario A. The first of the multiple, small perturbations

also involved the protect mission, so its impact followed the same pattern; it increase the preference frequency for advanced air + SOF over lean heavy to over one third in scenario A, but had almost no effect in scenario B. The second of the two smaller, broader perturbations involves the stabilize mission, which is also more important in scenario A than in the other scenarios, but is three times less important than protect in scenario A because of its defensive emphasis. Thus, it is not surprising that this perturbation has little effect on preference frequency, even in scenario A.

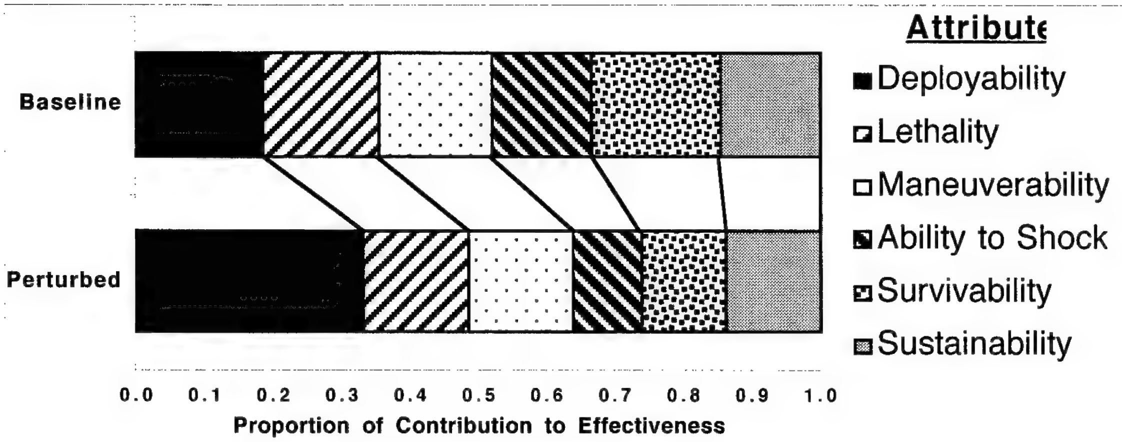


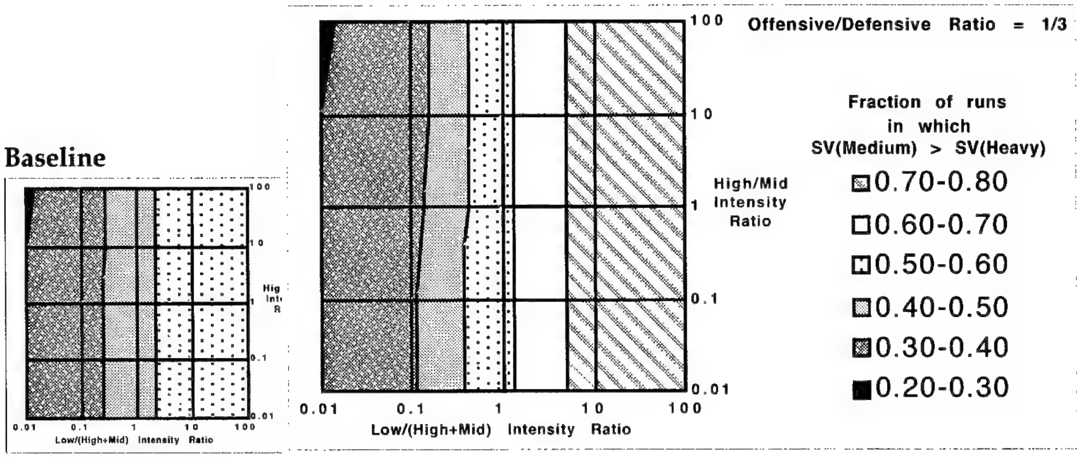

**Figure 10.4. Change in Distribution of Attribute Contributions to Effectiveness in the Protect Mission Due to a Large Increase in the Importance of Deployability Relative to Ability to Shock and Survivability**

The same perturbation—a large increase in the importance of deployability relative to ability to shock and survivability in the protect mission—had the greatest effect on the scenario preference frequencies in both time frames, as indicated by the shaded row in Tables 10.3 and 10.4. Figure 10.4 clearly shows how this perturbation alters the distribution of attribute contributions to effectiveness; the weight on deloyability is increased significantly, and the weight on the other two attributes is reduced. While the preference frequencies for the scenarios discussed above are representative, they only provide points estimates of impact within the much wider space of possibilities. The overall impact of a perturbation is portrayed more fully by constructing its new

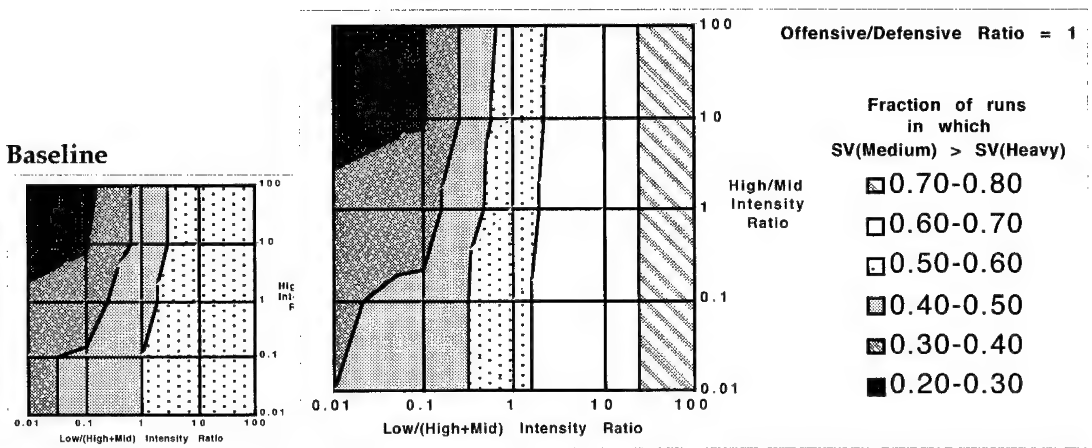
preference surface, and comparing it to the baseline surface. Figure 10.5 shows just such a comparison for medium versus heavy in the near term; the three new contour plots are shown with the corresponding plots for the baseline ratings inset on the left. These plots clearly illustrate how increasing the importance of deployability in the protect mission raised the "elevation" of the surface—the normalized preference frequency for medium over heavy—on the right-hand side of this space, where low-intensity missions are more important, especially in the upper slice, where the focus is on defensive missions. The 50-percent line, where the heavy and medium options are each preferred half of the time, was shifted substantially to the left. This implies that medium-weight forces would be preferred to heavy armored forces in most situations if low-intensity missions are more prevalent or important than other types of missions, unless those other missions are almost entirely high-intensity and offensively-oriented.

### Characteristic Rating Changes

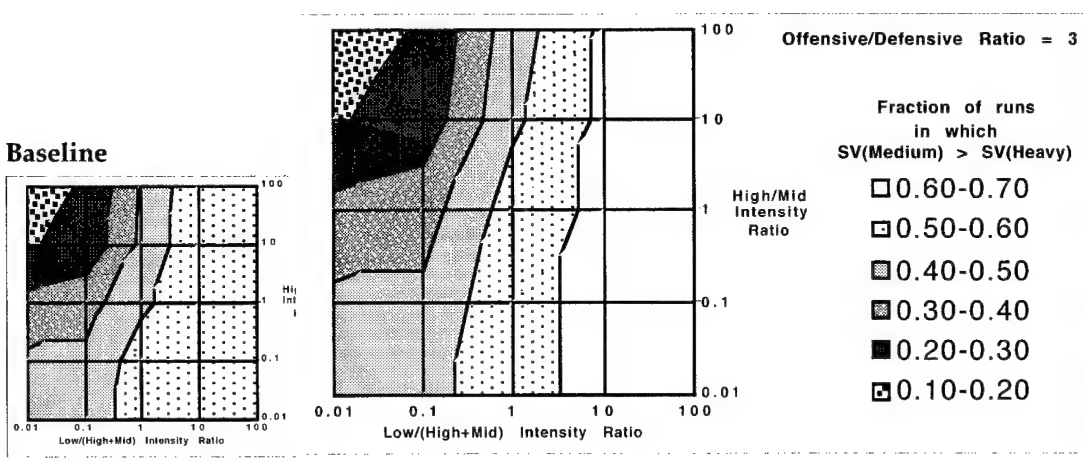
The characteristic ratings indicate how much the aggregate characteristics of a force contribute to its attributes, both individually and in combination. There are three sources of characteristic contributions: direct contributions from system characteristics, and from operational characteristics, as well as contributions due to synergistic interactions between system and operational characteristics. The experts rated all of these contributions, and their median ratings were used in the baseline analysis. These ratings are integrated to determine the normalized characteristic weights used to calculate the attribute values of every force option. As with the attribute ratings, two types of perturbations in the characteristic ratings were considered: large, controversial changes, and multiple small, influential changes. While many perturbations of both types were evaluated within each characteristic rating category, only a few of these are presented here. These perturbations were selected based on a few simple criteria, and the impact they had on option preferences.




(a)




(b)




(c)

**Figure 10.5. Preference Surface for Medium over Heavy in Near Term if Deployability is more important in Protect mission, when: (a) defensive missions are more important; (b) offensive and defensive are missions equally important; and (c) offensive missions are more important.**

*Large, Controversial Perturbations*

To identify candidates for large, controversial characteristic rating changes, the highest and lowest responses among the experts was recorded for each rating, and those that differed from the median value used in the analysis by 4 or more intervals (on the 0-to-9 scale) were considered. When there were several larger deviations in the ratings for the same attribute, or one of the deviations was very large (8 or more), this threshold was raised to 5 or even 6. Within each category of ratings (system, operational and synergistic), the largest deviations were evaluated separately, and the ones that had the greatest impact were combined together with others that involved either the same attribute or the same characteristic, or both in the case of synergistic ratings. Several such combinations were evaluated, and one or a few were chosen from each category based on their impact. However, any combination of changes that were not all based on the responses of the same individual or small group of experts was eliminated, even if it had a significant impact. All of the large, controversial perturbations selected in this manner, including the individual changes that comprise them, are shown in Table 10.7, along with their impact on option rankings in each time frame.

*SYSTEM.* The combination of large changes in system characteristic ratings selected for this category increases the contribution of mobility, firepower and protection to deployability from none to very strong, or slightly less (0 → 6, 7). Individually, these changes caused an average of 4 to 7.5 rank shifts per mission in the near term, and from 2.5 to 4.5 in the far term. When all three changes were combined in a single perturbation they led to an average of about 13 rank shifts per mission in the near term, and 6.6 in the far term. In the near term, these shifts favored heavy over medium: heavy gained 25 or more first-place spots in the halt, protect and raid missions, and 16 to 18 in the defend and stabilize missions, but only 4 in the evict mission, and established a clear advantage over medium in every mission. In the far term, lean heavy gained enough to always place second

in every mission, displacing advanced air + SOF from this position, and in turn bumping enhanced light from many of its third-place spots, especially in the protect and stabilize missions.

**Table 10.7**

**Impact of Selected Large, Controversial Perturbations in the Ratings of Characteristic Contributions to Force Attributes**

| | Average Rank Shifts per Mission | |
|---|---|---|
| **Changes in Characteristic Contributions to Attributes** | **Near Term** | **Far Term** |
| *SYSTEM* | | |
| Deployability – Mobility: 0 → 7 | 4.03 | 4.43 |
| Deployability – Firepower: 0 → 7 | 5.07 | 2.53 |
| Deployability – Protection: 0 → 6 | 7.47 | 3.47 |
| Deployability – Mobility: 0 → 7<br>Deployability – Firepower: 0 → 7<br>Deployability – Protection: 0 → 6 | 12.97 | 6.57 |
| *OPERATIONAL* | | |
| Deployability – Ability to Support: 7 → 0 | 1.93 | 3.37 |
| Deployability – Coordination: 5 → 0 | 2.87 | 1.73 |
| Deployability – Economy: 5 → 0 | 2.20 | 1.80 |
| Deployability – Ability to Support: 7 → 0<br>Deployability – Coordination: 5 → 0<br>Deployability – Economy: 5 → 0 | 9.13 | 8.73 |
| *SYNERGISTIC* | | |
| Ability to Shock – Self-sufficiency, Awareness: 0 → 7<br>Ability to Shock – Self-sufficiency, Coordination: 0 → 7 | 1.50 | 1.10 |
| Ability to Shock – Self-sufficiency, Economy: 1 → 7<br>Ability to Shock – Self-sufficiency, Ability to Support: 2 → 9 | 1.57 | 1.33 |
| Ability to Shock – Self-sufficiency, Awareness: 0 → 7<br>Ability to Shock – Self-sufficiency, Coordination: 0 → 7<br>Ability to Shock – Self-sufficiency, Economy: 1 → 7<br>Ability to Shock – Self-sufficiency, Ability to Support: 2 → 9 | 2.40 | 2.53 |

*OPERATIONAL*. The combination of large, controversial changes in the operational characteristic ratings selected for this category had the largest impact in both time frames, and all three of its rating changes were associated with the same expert. This perturbation decreases the contribution to deployability by coordination, economy, and ability to support from strong or very strong to none (5, 7 → 0). These fairly drastic changes did not have much impact individually, causing an average of less than 4 rank shifts per mission in both time frames, but

when combined in a single perturbation, they caused an average of over 9 rank shifts in the near term and 11 in the far term. In the near term, these changes favored medium over heavy, increasing medium's first-place frequency by 10 or more in every mission except evict. As a result, medium placed first two thirds of the time in the low-intensity protect and stabilize missions, almost 60 percent in the raid mission, 50 percent in the halt mission, 40 percent in the defend mission, but still just 10 in the evict mission. In the far term, this perturbation had an especially large impact in the two low-intensity missions: lean heavy lost 47 second-place spots in protect to end up with only 39 of 100, and lost 37 to end up with a total of 45 in stabilize. Advanced air + SOF picked up most of these spots, reaching a total of 45 in protect—enough for a plurality—and 36 in stabilize, while enhanced light also gained 15 second-place spots in protect and 13 in stabilize. The impact of this perturbation on the other missions in the far term was varied. Advanced air + SOF made gains on lean heavy of 20 rankings in raid, 10 in halt and 7 in defend, but none in evict, while enhanced light only gained a few third-place spots. These shifts still left lean heavy with a strong hold on second place in all four of these missions.

*SYNERGISTIC*. A large number of controversial changes in the synergistic interaction ratings were considered because these ratings are so numerous, and the experts had substantial disagreements on so many of them (see Table 6.2). Individually, these changes had little impact on their own, so they were combined in pairs that involved the same attribute and system or operational characteristics, or the same two characteristics. The pairs that had a noticeable impact were combined into groups of four that involved the same attribute and characteristic. The synergistic rating perturbation chosen from among these larger combinations had the largest impact, and was composed of the two most influential pairs of changes, which are shown along with it in Table 10.7. While this perturbation's individual changes were not all based on the responses of the same expert, the two component pairs were each associated with one of two experts who gave quite similar responses on all four of the ratings involved. This

set of changes increases the contributions to ability to shock from interactions between self-sufficiency and awareness, coordination, economy and ability to support from between none and moderate to very or extremely strong (0, 1, 2 → 7, 9). This perturbation had only a modest impact, with an average of around 2.5 rank shifts per mission in both time frames. In the near term, the largest shift moved just 5 first-place rankings from heavy to medium in the defend and raid missions. In the far term, the mission most affected was protect, in which lean heavy lost 8 second-place spots; 5 to enhanced light and 3 to advanced air + SOF.

*Small, Influential Perturbations*

The selection process for combinations of small, influential characteristic rating changes was somewhat different from the approach used to select large, controversial changes. These combinations are small because they are composed of individual changes of plus or minus one scale interval. The components of the combinations considered are influential, because they had they largest effects on their own. Because there are so many characteristic ratings, average differential effect (ADE) values were calculated for every possible small rating change, and then used to determine which changes are the most influential. Within each category of ratings (system, operational and synergistic), the most influential ratings were combined into groups based on attributes or characteristics. The impact that each such combination of small, influential changes had on option rankings was calculated and compared.

None of the combinations of operational or synergistic ratings that were considered caused more than 2 rank shifts per mission in either time frame. Some combinations of system characteristic rating changes did, however, have a more substantial impact. Two sets of four such changes were selected based on their impact; positive and negative shifts were applied to each set, both individually and in combination. Table 10.8 shows the six resulting perturbations and their impact in each time frame. The first set of four changes affect the contributions of stealth to lethality, maneuverability, ability to shock, and

survivability—the four dominance attributes. The second set of changes involve the contributions of self-sufficiency to these same four attributes.

In the near term, the impact of slightly increasing or decreasing all of these ratings was roughly the same. Changing the stealth ratings in either direction caused about 2.6 rank shifts per mission, while decreasing the self-sufficiency ratings had a larger impact that increasing them—an average of almost 5 rank shifts versus less than 3.5. When both sets of ratings were decreased together the impact, an average of 5.4 rank shifts, was slightly larger than the 4.5 rank shifts caused when all of the ratings were increased. The combined decrease shifted about 10 first-place spots from medium to heavy in every mission, except stabilize, where there were only a few shifts. These shifts were sufficient to put heavy ahead of medium in the protect mission, and solidified its lead in the other non-low-intensity missions. Not surprisingly, the combined increase perturbation had essentially the opposite effect: heavy's first-place frequency was reduced in every mission, with most of these lost spots going to medium. The size of these shifts differed across missions according to intensity: heavy lost 11 shifts in halt and evict (high-intensity), 7 to 9 in defend and raid (mid-intensity), and 4 to 5 protect and stabilize (low-intensity), which was enough for medium to take the lead in raid, and extend its lead in protect and stabilize.

In the far term, the difference between these two opposing perturbations was clearer and their effects were reversed; the two sets of changes had more impact when they were increased than when they were decreased, both on their own and together. Increasing the stealth ratings caused 2.9 rank shifts per mission, while decreasing them led to just over 2. Similarly, increasing the self-sufficiency ratings resulted in about 4.6 shifts, while decreasing them caused only 3.0 shifts, on average, per mission. Increasing the ratings in both sets led to almost 6.2 rank shifts per mission, as opposed to only about 3.3 when all of the ratings were decreased. The combined increase shifted second-place spots from lean heavy to advanced air + SOF, and in the low-intensity missions, where these

shifts exceeded 25, a significant fraction of the lost spots went to enhanced light. In spit of these substantial shifts, however, lean heavy still ended up in second place most often in every mission, even in the low-intensity missions where its frequency in this position was over 55 percent, compared to around 30 percent for advanced air + SOF and 10 to 20 percent for enhanced light.

**Table 10.8**

**Impact of Selected Combinations of Small, Influential Changes in the System Characteristic Contribution Ratings**

| Changes in Characteristic Contribution Ratings | Average Rank Shifts per Mission | |
|---|---|---|
| | Near Term | Far Term |
| Lethality – Stealth: 4 → 5 (+)<br>Maneuverability – Stealth: 5 → 6 (+)<br>Ability to Shock – Stealth: 6 → 7 (+)<br>Survivability – Stealth: 8 → 9 (+) | 2.67 | 2.90 |
| Lethality – Self-sufficiency: 3 → 4 (+)<br>Maneuverability – Self-sufficiency: 4 → 5 (+)<br>Ability to Shock – Self-sufficiency: 3 → 4 (+)<br>Survivability – Self-sufficiency: 4 → 5 (+) | 3.43 | 4.57 |
| Lethality – Stealth: 4 → 5 (+)<br>Maneuverability – Stealth: 5 → 6 (+)<br>Ability to Shock – Stealth: 6 → 7 (+)<br>Survivability – Stealth: 8 → 9 (+)<br>Lethality – Self-sufficiency: 3 → 4 (+)<br>Maneuverability – Self-sufficiency: 4 → 5 (+)<br>Ability to Shock – Self-sufficiency: 3 → 4 (+)<br>Survivability – Self-sufficiency: 4 → 5 (+) | 4.47 | 6.17 |
| Lethality – Stealth: 4 → 3 (–)<br>Maneuverability – Stealth: 5 → 4 (–)<br>Ability to Shock – Stealth: 6 → 5 (–)<br>Survivability – Stealth: 8 → 7 (–) | 2.57 | 2.07 |
| Lethality – Self-sufficiency: 3 → 2 (–)<br>Maneuverability – Self-sufficiency: 4 → 3 (–)<br>Ability to Shock – Self-sufficiency: 3 → 2 (–)<br>Survivability – Self-sufficiency: 4 → 3 (–) | 4.93 | 3.03 |
| Lethality – Stealth: 4 → 3 (–)<br>Maneuverability – Stealth: 5 → 4 (–)<br>Ability to Shock – Stealth: 6 → 5 (–)<br>Survivability – Stealth: 8 → 7 (–)<br>Lethality – Self-sufficiency: 3 → 2 (–)<br>Maneuverability – Self-sufficiency: 4 → 3 (–)<br>Ability to Shock – Self-sufficiency: 3 → 2 (–)<br>Survivability – Self-sufficiency: 4 → 3 (–) | 5.40 | 3.27 |

*Impact of Selected Perturbations on Option Preferences*

The shaded rows in Tables 10.7 and 10.8 highlight the combined perturbations selected in each category for the large, controversial characteristic rating changes, and the combined positive and negative perturbations for the most influential sets of small rating changes. As with the attribute rating perturbations, the impact of these selected characteristic rating perturbations on the scenario preference frequencies is examined in each time frame. Table 10.9 shows the preference frequency shifts for the designated near-term option pair, medium versus heavy, while Table 10.10 shows them for the far-term comparison between advanced air + SOF and lean heavy. These results are discussed separately for each time frame.

The selected system rating perturbation, which greatly increases the contributions of mobility, firepower and protection to deployability, has a substantial impact in the near term. In all three scenarios, it cuts the frequency with which medium is preferred to heavy in half, leaving heavy with a clear advantage. The selected operational perturbation substantially reduces the contributions of mobility, firepower and protection to deployability. It also has a significant effect on the scenario preference frequencies for medium versus heavy in the near term. This perturbation, however, favors medium, increasing its preference frequency in all three scenarios, enabling it to exceed 70 percent in scenario A, almost reach three fifths percent in scenario B, and surpass one third in scenario C. The selected synergistic perturbation introduces a substantial contribution to ability to shock due to synergistic interactions between self-sufficiency and all of the operational characteristics except adaptability. This set of changes has no impact on the near-term preference frequencies in scenario A, and increases them only slightly in favor of medium in the other two scenarios. The combination of small increases in the contributions of stealth and self-sufficiency to the four dominance attributes caused a small increase in the preference frequency for medium in scenario A, and somewhat larger increases

in the other two scenarios, putting medium over 50 percent in scenario B, and getting it up to over one third in scenario C. The same combination of decreases had a more even effect, pushing the preference frequency down about 0.10 in all three scenarios, thus allowing heavy to have an advantage in every scenario.

**Table 10.9**

**Scenario Preference Frequencies for Medium Versus Heavy in the Near Term, Under Selected Characteristic Rating Perturbations**

| Perturbation in Characteristic Contribution Ratings | Preference Frequencies in Future Scenarios | | |
|---|---|---|---|
| | (A) Small-Scale Interventions | (B) Balanced Mix of Contingencies | (C) Major Regional Conflicts |
| SYSTEM<br>Large increase in contribution of Mobility, Firepower and Protection to Deployability | 0.58 → 0.29 | 0.42 → 0.21 | 0.23 → 0.12 |
| OPERATIONAL<br>Large decrease in contribution of Coordination, Economy and Ability to Support to Deployability | 0.58 → 0.72 | 0.42 → 0.58 | 0.23 → 0.34 |
| SYNERGISTIC<br>Large increase in contribution to Ability to Shock due to interaction between Self-sufficiency and Awareness, Coordination, Economy and Ability to Support | 0.58 → 0.58 | 0.42 → 0.45 | 0.23 → 0.28 |
| SYSTEM<br>Small increase in contribution of Stealth and Self-sufficiency to Lethality, Maneuverability, Ability to Shock and Survivability | 0.58 → 0.61 | 0.42 → 0.53 | 0.23 → 0.34 |
| SYSTEM<br>Small decrease in contribution of Stealth and Self-sufficiency to Lethality, Maneuverability, Ability to Shock and Survivability | 0.58 → 0.47 | 0.42 → 0.33 | 0.23 → 0.12 |

In the far term, the set of large, controversial changes chosen for the system characteristic ratings favored lean heavy, driving the preference frequency for advanced air + SOF over this option down to zero in all three scenarios. As in the near term, the selected set of operational changes had the opposite effect, favoring advanced air + SOF, though not enough for it to gain an advantage in any of the scenarios; the preference frequency rose as high as 0.44

in scenario A, and doubled to 12 percent in scenario B, but only barely peeked above zero in scenario C. Again, the synergistic perturbation did not have a significant impact, raising the preference frequency by only 0.03 in scenario A, and even less in the other scenarios. The broad set of small increases in system characteristic ratings had a fairly significant effect: the preference frequency rose to 30 percent in scenario A, 12 percent in scenario B, and 4 percent in scenario C. When these same ratings were all slightly decreased, the effect was reversed, and the frequency was driven down to just 7 percent in scenario A, and all the way to zero in the other two scenarios.

**Table 10.10**

**Scenario Preference Frequencies for Advanced Air + SOF Versus Lean Heavy in the Far Term, Under Selected Characteristic Rating Perturbations**

| **TYPE OF RATING** **Characteristic Contribution Rating Perturbation** | **Preference Frequencies in Future Scenarios** | | |
|---|---|---|---|
| | (A) Small-Scale Interventions | (B) Balanced Mix of Contingencies | (C) Major Regional Conflicts |
| SYSTEM <u>Large increase</u> in contribution of Mobility, Firepower and Protection to Deployability | 0.12 → 0.00 | 0.06 → 0.00 | 0.00 → 0.00 |
| OPERATIONAL <u>Large decrease</u> in contribution of Coordination, Economy and Ability to Support to Deployability | 0.12 → 0.44 | 0.06 → 0.12 | 0.00 → 0.02 |
| SYNERGISTIC <u>Large increase</u> in contribution to Ability to Shock due to interaction between Self-sufficiency and Awareness, Coordination, Economy and Ability to Support | 0.12 → 0.15 | 0.06 → 0.07 | 0.00 → 0.00 |
| SYSTEM <u>Small increase</u> in contribution of Stealth and Self-sufficiency to Lethality, Maneuverability, Ability to Shock and Survivability | 0.12 → 0.30 | 0.06 → 0.12 | 0.00 → 0.04 |
| SYSTEM <u>Small decrease</u> in contribution of Stealth and Self-sufficiency to Lethality, Maneuverability, Ability to Shock and Survivability | 0.12 → 0.07 | 0.06 → 0.00 | 0.00 → 0.00 |

The large, controversial perturbation in the operational characteristic contribution ratings is highlighted in Tables 10.9 and 10.10 because it is the most influential and, arguably, the most plausible of the five selected perturbations. It has the largest impact on the scenario preference frequencies in both time frames, especially in scenario A, which emphasizes defensive and low-intensity missions. This particular change is also interesting because it reduces the contributions of three operational characteristics to deployability that are among the largest contributors to this attribute in the baseline case, as Figure 10.6 shows quite clearly. One could argue, however, that these contributions are much too high. The ability to deploy a force might rely more on the physical properties of its systems (transportability) and the amount of initial supplies and equipment they require (self-sufficiency), together with the quality of its preparation and training (adaptability), rather than operational interaction and efficiency upon arrival (coordination, economy and ability to support). Figure 10.6 shows the degree to which this perturbation changes the overall distribution of contributions to deployability, increasing the weight placed on transportability, self-sufficiency and adaptability to make them the three largest contributors, while drastically reducing the contributions of coordination, economy and ability to support.

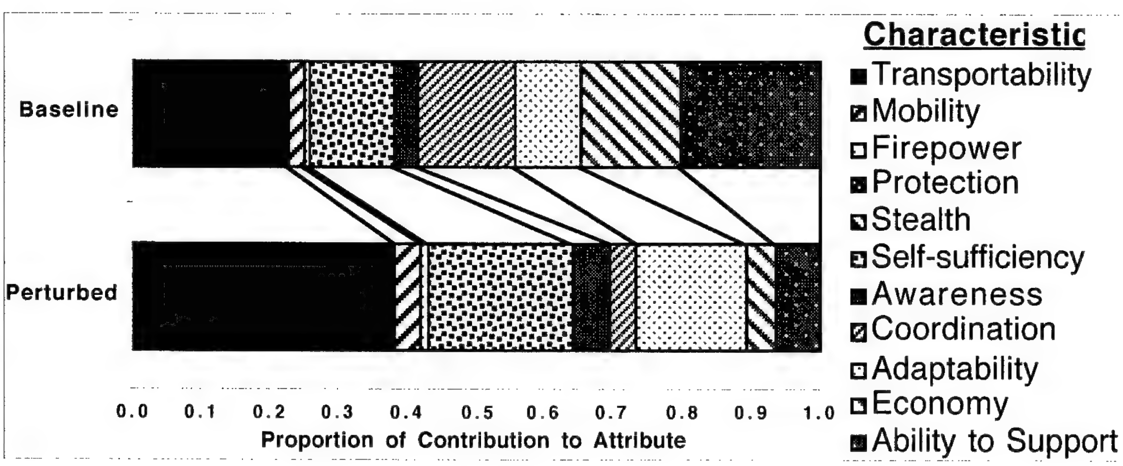



**Figure 10.6. Change in Distribution of Characteristic Contributions to Deployability Due to a Large Decrease in the Contributions from Coordination, Economy and Ability to Support**

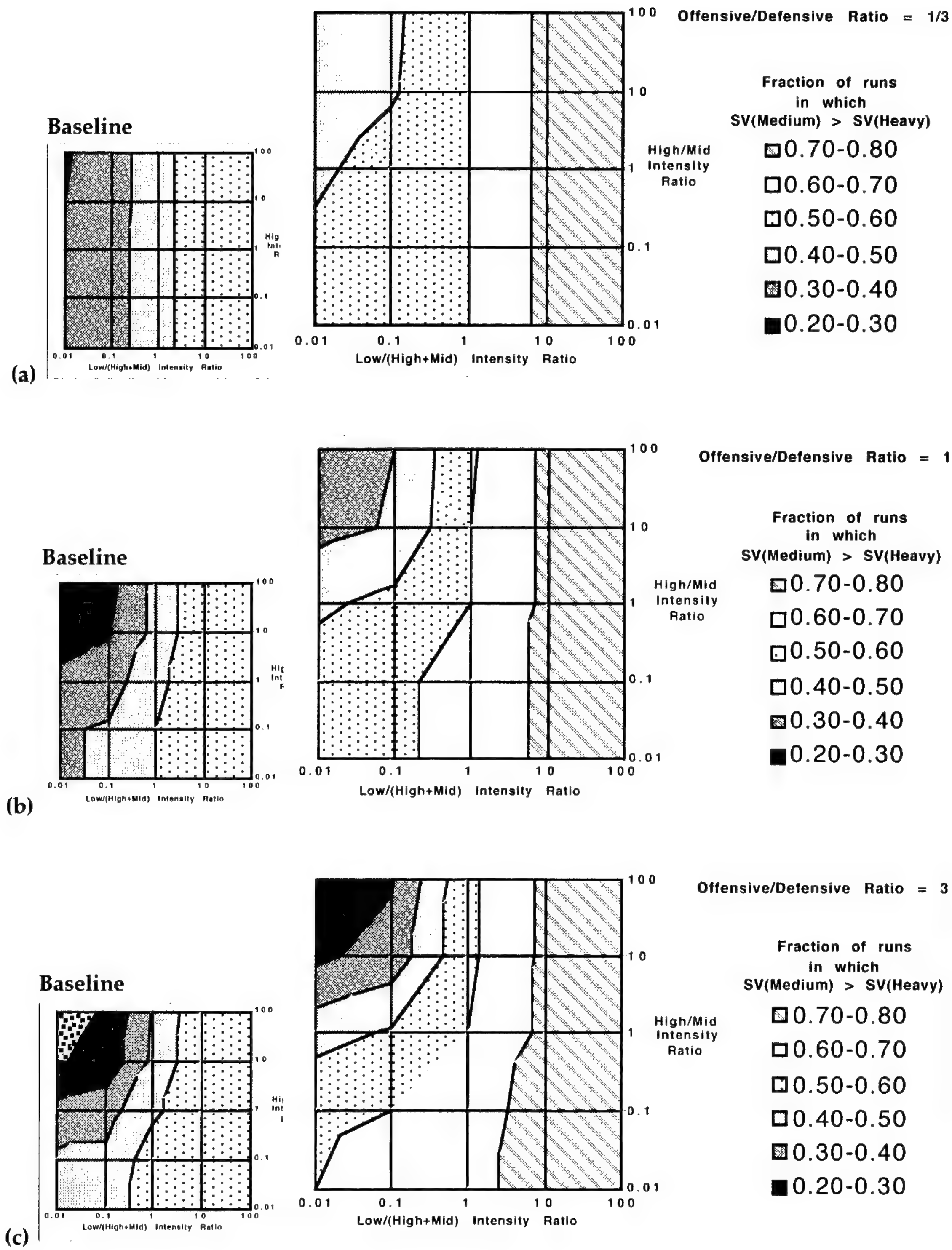



**Figure 10.7. Preference Surface for Medium over Heavy in Near Term if Coordination, Economy and Ability to Support Contribute less to Deployability, when: (a) defensive missions are more important; (b) offensive and defensive are missions equally important; and (c) offensive missions are more important.**

Figure 10.7 further illustrates the impact of this perturbation by showing its effect on the preference surface for medium versus heavy in the near term. The shape of this surface remains similar to that of the baseline surface, except that elevation is increased quite uniformly, by between 0.10 and 0.20, throughout the parameter space. As a result of these changes in the operational characteristic ratings for deployability, medium is preferred to heavy a majority of the time, unless high-intensity missions are considerably more important than other types of missions, as indicated by the 0.50 contour in all three slices of the parameter space in Figure 10.7. Moreover, the higher elevations on the right-hand side of these three contour plots indicate that medium is preferred to heavy at least 60 percent of the time if low-intensity missions are more important than non-low-intensity missions.

**System Role Importance Rating Changes**

The system role importance ratings are used, in conjunction with quantity weights based on the number of each system type in a force option, to aggregate the characteristic values of these component systems to determine the option's force-level characteristics. As with the characteristic ratings, the median expert response for each system role importance rating determines the value used for that rating in the analysis. Many combinations of both large, controversial and small, influential changes in these ratings were also considered, and a few of each type, chosen in a similar manner, are presented and discussed here.

*Large, Controversial Perturbations*

The combinations of controversial changes considered for this category of ratings were constructed based on the system roles they involved. Each of the expert's responses for these ratings tended to be similar within three groups of roles: (1) direct fire, attack and support, and indirect fire, close and far; (2) close air support, and deep air interdiction; and (3) reconnaissance, scout and strike, and special operations. The expert responses that deviated the most from the

median value for each rating were noted, and the largest among these were combined within a group of roles if they involved the same system characteristic. Because of the grouping requirement, and the fact that the most extreme deviations in some ratings were relatively small, the rating changes in these combinations varied considerably in size, with some as small as 3 or even 2. Several such perturbations were considered for each role group. Those that consisted of changes based on (or very close to) the responses of the same expert, and had the most impact, were selected for closer examination, and are shown in Table 10.11 along with their impact in each time frame. None of these perturbations involve changes in the ratings for the third group of roles, reconnaissance and special operations, since the changes in this group either did not have much impact, or were associated with different experts. The first four perturbations involve the direct and indirect fire roles, while the final two affect the air roles.

*Transportability More Important in Fire Roles.* The first perturbation increases the importance of transportability in the four fire roles from near moderate to a bit more or a bit less than very strong (2, 3, 4 → 6, 8). This set of increases had a moderate impact in both time frames: an average of almost 8 rank shifts per mission in the near term, and over 5 in the far term. In the near term, increasing the importance of transportability caused between 15 and 20 first-place spots to shift from heavy to medium in every mission except evict, where it only led to 10. These shifts extended medium's advantage in the low-intensity missions to a first-place frequency of 70 percent, and gave it a clear advantage in the raid mission, with 65 percent, as well as a slim majority in the halt mission. This left heavy as the top choice only in evict, with over three quarters of the first-place spots, and in defend, where it placed first exactly half of the time. In the far term, making transportability more important in the direct and indirect fire roles had mixed results: lean heavy lost 25 to 30 second-place spots in the low-intensity protect and stabilize missions, but lost fewer than 10 in the other missions, and none at all in the evict mission. These shifts still left lean heavy in

second place most often, although advanced air + SOF managed to place second over a quarter of the time in stabilize, and over a third of the time in protect.

**Table 10.11**

**Impact of Selected Large, Controversial Perturbations in the System Role Importance Ratings**

| Changes in System Role Importance Ratings | Average Rank Shifts per Mission | |
|---|---|---|
| | Near Term | Far Term |
| Direct Fire Attack – Transportability: 2 → 6<br>Direct Fire Support – Transportability: 3 → 6<br>Indirect Fire Close – Transportability: 4 → 6<br>Indirect Fire Far – Transportability: 3 → 8 | 7.73 | 5.13 |
| Direct Fire Attack – Transportability: 2 → 0<br>Direct Fire Support – Transportability: 3 → 0<br>Indirect Fire Close – Transportability: 4 → 0<br>Indirect Fire Far – Transportability: 3 → 0 | 10.77 | 3.90 |
| Direct Fire Attack – Stealth: 4 → 8<br>Direct Fire Support – Stealth: 5 → 9<br>Indirect Fire Close – Stealth: 5 → 7<br>Indirect Fire Far – Stealth: 3 → 6 | 3.40 | 6.33 |
| Direct Fire Attack – Self-sufficiency: 5 → 1<br>Direct Fire Support – Self-sufficiency: 5 → 1<br>Indirect Fire Close – Self-sufficiency: 4 → 1<br>Indirect Fire Far – Self-sufficiency: 3 → 1 | 17.33 | 7.87 |
| Close Air Support – Transportability: 7 → 1<br>Deep Air Interdiction – Transportability: 7 → 1 | 10.77 | 17.23 |
| Close Air Support – Self-sufficiency: 3 → 9<br>Deep Air Interdiction – Self-sufficiency: 3 → 9 | 13.70 | 14.30 |

*Transportability Less Important in Fire Roles.* The second perturbation decreases the transportability ratings for the fire roles down to none (2, 3, 4 → 0). These decreases had more impact in the near term, with an average of nearly 11 rank shifts, and less in the far term, with less than 4. In the near term, reducing the importance of transportability led to even larger shifts in the opposite direction: heavy gained over 20 first-place spots in every mission but evict, picking up 35 or more in protect and raid. These gains were mostly at the expense of medium, which was pushed out of contention in every mission, winning only a third of the time in stabilize, and just over a fifth of the time in protect, its two best missions. In the far term, this perturbation also enabled lean heavy to place second all the time, in every mission, even protect and stabilize.

*Stealth More Important in Fire Roles.* The third perturbation increases the importance of stealth from between moderate and strong to levels ranging from a bit higher than strong to extremely strong (3, 4, 5 → 6, 7, 8, 9) in the four direct and indirect fire roles. This set of changes had a fairly small impact overall in the near term, with an average of just 3.4 rank shifts per mission, while in the far term, it had a somewhat larger impact, with an average of over 6. The near-term effects were modest, shifting fewer than 10 first-place spots from heavy to medium in each mission. In the raid mission, however, this shift was sufficient for medium to surpass heavy and win half of the time. Medium's first-place frequency did not exceed 60 percent in the low-intensity missions, was under 40 in halt and defend, and under 20 in evict. In the far term, the effects of this perturbation were more substantial: lean heavy lost over 30 second-place spots in the two low-intensity missions, and between 7 and 10 in the other missions, except evict, which was unchanged. Advanced air + SOF gained most of these spots, although enhanced light picked up 9 in both protect and stabilize. However, these shifts still left lean heavy in second most often in every mission: 100 percent of the time in evict, over 80 percent in halt, defend and raid, but only about 50 percent of the time in protect and stabilize. Advanced air + SOF placed second over 35 percent of the time in the two low-intensity missions, with enhanced light picking up the 10 to 15 remaining spots.

*Self-sufficiency Less Important in Fire Roles.* The fourth perturbation that affects this group of roles decreases the importance of self-sufficiency from between moderate and strong to minimal (3, 4, 5 → 1). The overall impact of this set of changes was quite large in the near term, where there was an average of over 17 rank shifts per mission, and moderate in the far term, with an average of nearly 8. In the near term, this change hurt the medium option the most, causing it to lose about 20 first-place spots in its three best missions, protect, stabilize and raid, along with 12 spots in halt and defend, and 6 in evict. Some of these losses were picked up by heavy, but many of them went to air + SOF, which also made

considerable gains in second place by pushing medium and heavy into third place quite often. This left heavy in first most often in every mission, with around 50 percent even in its two worst missions, protect and stabilize. Medium won only about a third of the time in these two low-intensity missions, with even lower frequencies in the other missions, but still placed second more often than any of the other options. Air + SOF ended up with between 10 and 20 of the first-place spots in every mission except evict, and just about as many second-place spots in every mission as well. The air only option also benefited from this perturbation, picking up about 20 fourth-place spots from the light option in every mission to achieve totals of 30 to 50. In the far term, lean heavy lost less than 10 second-place spots in every mission, with advanced air + SOF gaining all of them, plus an additional 5 at the expense of enhanced light in the stabilize mission. Enhanced light also lost between 14 and 18 third-place spots in every mission except evict, leaving it with just 1 in raid, 10 in protect, 13 in stabilize, and none in any other mission. In spite of these shifts, lean heavy still placed second far more often than advanced air + SOF, beating it three quarters of the time in its two best missions, protect and stabilize.

*Transportability Less Important in Air Roles.* The first set of changes in the ratings for close air support and deep air interdiction decreases the importance of transportability from very strong to minimal (7 → 1). In both time frames this perturbation had a fairly large impact, with an average of almost 11 rank shifts per mission in the near term, and over 17 in the far term. In the near term, medium gained around 20 first-place spots in every mission except evict, where it gained 10, all mostly from heavy. Advanced air + SOF also made gains versus heavy for second place, especially in the low-intensity missions. As a result, medium ended up in first place around 70 percent of the time in protect, stabilize and raid, and even surpassed heavy in halt, with 56 percent, and in defend, with 48, although it was still well behind in evict, with less than 20. Air + SOF also made a better showing in the top two: it won 5 to 10 first-place spots in every mission, and took more than 20 second-place spots in the low-intensity missions,

and 10 to 15 in the other non-evict missions. In the far term, the effects of this perturbation were quite dramatic. Lean heavy lost 60 to 70 second-place spots in protect and stabilize, and about 50 in raid, 40 in halt and 20 in defend. Most of these spots went to advanced air + SOF, except in the two low-intensity missions, where enhanced light picked up about 20 of them. Lean heavy still had the most second-place spots after this change, with all 100 in evict, 75 in defend, and 56 in halt, but medium surpassed it in the other three missions, winning 64 in stabilize, 55 in protect, and 49 in raid. In fact, enhanced light even won more second-place spots than lean heavy in the low-intensity missions, with about a fifth of them in protect, and a quarter in stabilize.

*Self-sufficiency More Important in Air Roles.* The second change in the air role ratings increases the importance of self-sufficiency in these roles from moderate to extremely strong (3 → 9). This perturbation also had a large impact, causing an average of around 14 rank shifts per mission in both time frames. In the near term, heavy benefited the most from this change, gaining 17 to 20 first place spots, mostly from medium, in every mission except evict, where it gained 10. This change gave heavy a solid lead for first in every mission, with medium only winning 30 to 40 percent of the time in protect, stabilize and raid, its best three missions. The air only option also benefited from this perturbation, gaining 5 to 10 fourth-place spots from light and air + SOF to give it totals ranging from 15 for stabilize to 40 for evict, plus between 5 and 10 thirds in every mission as well. In the far term, enhanced light gained the most, picking up between a quarter and a third of the third-place spots from advanced air + SOF in every mission except evict, where it gained about a sixth of them. Advanced air + SOF also lost its first place spots to lean heavy, with enhanced light displacing it in the low-intensity missions. As a result, lean heavy remained the undisputed second-best choice in every mission. The real contest, however, was for third. Enhanced light gained enough spots to have a clear majority in the low-intensity missions, while advanced air + SOF still prevailed most often in the other missions, although enhanced light placed third at least 40 percent of the time in every one but evict.

**Table 10.12**

**Impact of Selected Small, Multiple Perturbations in the System Role Importance Ratings**

| Changes in System Role Importance Ratings | Average Rank Shifts per Mission | |
|---|---|---|
| | Near Term | Far Term |
| Close Air Support – Mobility: 7 → 6 (–)<br>Close Air Support – Self-sufficiency: 3 → 4 (+)<br>Deep Air Interdiction – Mobility: 8 → 7 (–)<br>Deep Air Interdiction – Self-sufficiency: 3 → 4 (+) | 4.567 | 6.567 |
| Close Air Support – Mobility: 7 → 8 (+)<br>Close Air Support – Self-sufficiency: 3 → 2 (–)<br>Deep Air Interdiction – Mobility: 8 → 9 (+)<br>Deep Air Interdiction – Self-sufficiency: 3 → 2 (–) | 3.767 | 6.800 |
| Close Air Support – Protection: 4 → 3 (–)<br>Close Air Support – Stealth: 5 → 6 (+)<br>Deep Air Interdiction – Protection: 3 → 2 (–)<br>Deep Air Interdiction – Stealth: 6 → 7 (+) | 3.633 | 3.800 |
| Close Air Support – Protection: 4 → 5 (+)<br>Close Air Support – Stealth: 5 → 4 (–)<br>Deep Air Interdiction – Protection: 3 → 4 (+)<br>Deep Air Interdiction – Stealth: 6 → 5 (–) | 2.600 | 5.067 |
| Close Air Support – Mobility: 7 → 6 (–)<br>Close Air Support – Protection: 4 → 3 (–)<br>Close Air Support – Stealth: 5 → 6 (+)<br>Close Air Support – Self-sufficiency: 3 → 4 (+)<br>Deep Air Interdiction – Mobility: 8 → 7 (–)<br>Deep Air Interdiction – Protection: 3 → 2 (–)<br>Deep Air Interdiction – Stealth: 6 → 7 (+)<br>Deep Air Interdiction – Self-sufficiency: 3 → 4 (+) | 7.367 | 11.033 |
| Close Air Support – Mobility: 7 → 8 (+)<br>Close Air Support – Protection: 4 → 5 (+)<br>Close Air Support – Stealth: 5 → 4 (–)<br>Close Air Support – Self-sufficiency: 3 → 2 (–)<br>Deep Air Interdiction – Mobility: 8 → 9 (+)<br>Deep Air Interdiction – Protection: 3 → 4 (+)<br>Deep Air Interdiction – Stealth: 6 → 5 (–)<br>Deep Air Interdiction – Self-sufficiency: 3 → 2 (–) | 7.800 | 13.333 |

*Small, Influential Perturbations*

Combinations of small, influential changes in the system role importance ratings were also constructed from individual changes that affected the three role groups discussed above. Small changes of one rating interval were made in each system role importance rating, and the ADE values for each of these changes were calculated and compared. Those with the largest impact on their own were

combined with each other if they were in the same group. Sometimes, where appropriate, these combinations only involved a subset of the roles in a group. For example, some perturbations only changed the ratings for the two direct fire roles, not for all four fire roles. From among all of the combinations evaluated, several that involved the ratings for the two air roles were selected. These perturbations are shown in Table 10.12, together with their overall impact on the option rankings in each time frame.

*Importance of Mobility and Self-sufficiency in Air Roles.* The first two of the selected perturbations change the importance of mobility and self-sufficiency in the two air roles, moving them in opposite directions. The first one makes mobility less important, and self-sufficiency more important, while the second one increases the importance of mobility and decreases the importance of self-sufficiency. Both of these perturbations had only a modest impact in the near term, with an average of less than 5 rank shifts per mission, but had somewhat more impact in the far term, with well over 6 rank shifts per mission. In the near term, the shift in importance from mobility to self-sufficiency aided heavy and air only a bit at the expense of air + SOF and light, but none of these shifts only amounted to more than a handful of runs. In the far term, this same perturbation led to similarly small shifts in favor of lean heavy for second place, but enhanced light gained around 10 third-place spots from advanced air + SOF in every mission, exceeding a total of 40 in both low-intensity missions. The opposite perturbation also had fairly modest effects, especially in the near term, where it led to just a few shifts in first place from heavy to medium—enough to put medium slightly ahead in the raid mission. In the far term, however, there were some larger shifts: lean heavy lost 18 second-place spots in the low-intensity missions, which enabled advanced air + SOF to place second almost a third of the time in these two missions.

*Importance of Protection and Stealth in Air Roles.* The next two perturbations both involved changes in the importance of protection and stealth in the two air

roles, with the first shifting importance from protection to stealth, and the second shifting it from stealth to protection. The first of these perturbations, which favors stealth, had about the same fairly low impact in both time frames, causing an average of a bit less than 4 rank shifts per mission, while the second, which favors protection, had more impact in the far term, with about 5 rank shifts per mission, compared to just 2.6 in the near term. In the near term, making stealth more important relative to protection in the air roles enabled heavy to gain between 2 and 8 first-place spots, but these shifts were not enough for it to overtake medium in protect or stabilize. In the far term, this perturbation helped lean heavy by about the same amount, further solidifying its hold on second place, but also enabled enhanced light to pick up 4 to 10 third-place spots, mostly from advanced air + SOF, exceeding a total of 30 in the low-intensity missions. Making protection a bit more important relative to stealth had small but significant effects in the near term, shifting a few first-place spots from heavy to medium in each mission, enabling medium gain the lead from heavy in the raid mission. In the far term, this perturbation caused lean heavy to lose ground, especially in the low-intensity missions, where it lost around 20 spots, ending up with a less commanding majority of about 60 in these missions. Most of these spots went to advanced air + SOF, which reached a total of almost 30 in protect and stabilize.

*Importance of Mobility, Self-sufficiency, Protection and Stealth in Air Roles.* The last two perturbations shown in Table 10.12 combine the four sets of changes discussed above. The first one increases the importance of stealth and self-sufficiency, while decreasing that of mobility and protection in air roles. The second does the opposite, favoring mobility and protection more, and favoring stealth and self-sufficiency less. Both perturbations have a moderate impact in the near term, with an average of 7 to 8 rank shifts per mission, and a somewhat larger impact in the far term—11 shifts for the former, and 13 for the latter. In the near term, the first combined perturbation benefited heavy, increasing its first-place frequency by as many as 12 spots in some missions. A few of these

spots consistently came from air + SOF, while the rest came from medium, which retained its lead in stabilize, still placing first over 50 percent of the time. Heavy gained enough spots, however, to take the lead from medium in protect, which it won over half the time, while also extending its lead over medium in the other four missions. In the far term, this first combination of changes gave lean heavy enough additional second-place spots in all of the missions, even the low-intensity ones, to be the next-best option after future medium nearly all the time. This perturbation also favored enhanced light, which picked up 20 or more spots from advanced air + SOF in every mission except evict, giving it the lead in the two low-intensity missions, with over 50 percent in protect and over 45 percent in stabilize, and brought it much closer, with 35 to 40 percent, in the remaining missions other than evict, where its total did not exceed 20 percent. The second combined perturbation, not surprisingly, had essentially the opposite effects in both time frames. In the near term, heavy lost between 5 and 15 first-place spots in every mission, with a handful going to air + SOF, and the rest to medium. These shifts gave medium the lead for first in raid, which it won exactly half the time, extended its lead in protect and stabilize, and pushed its first-place totals up to 35 to 40 percent in halt and defend, and almost 20 percent in evict. In the far term, this second perturbation had a fairly dramatic impact, shifting over 40 second-place spots from lean heavy to advanced air + SOF in the low-intensity missions, and around 20 in the other non-evict missions. This gave advanced air + SOF the lead in protect and stabilize, with second-place frequencies of around 60 percent, but lean heavy retained an advantage in the non-low-intensity missions, still placing second nearly all the time in evict, and over 70 percent of the time in the other three missions.

*Impact of Selected Perturbations on Option Preferences*

A total of four perturbations in the system role importance ratings are examined more closely here. These include the two sets of large, controversial changes highlighted in Table 10.11, and the two largest combinations of small,

influential changes highlighted in Table 10.12. The impact of these perturbations on the preference frequencies (for the selected options pair in each time frame) are shown in Table 10.13 for the near term, and in Table 10.14 for the far term. Before discussing these results, it is worth pointing out that the two large, controversial perturbations were selected based on two factors: distribution of impact, and plausibility.

Among the four sets of changes in the ratings for the fire roles, the one that increased the importance of transportability was the clear choice, even though its overall impact, while substantial, was not the largest in either time frame. This impact, however, was focused on the pairs of options being compared—medium and heavy in the near term, and lean heavy and advanced air + SOF in the far term—and its implications were more plausible than the other perturbations. Increasing the importance of transportability in the fire roles helped medium make gains on heavy in the near term, and allowed advanced air + SOF to catch up with lean heavy to some degree in the far term. The other three perturbations involving the same roles also affected these option pairs, sometimes with even greater effect, but their impact was spread out more over the other options. The real attraction of this choice, however, was its plausibility. The baseline ratings for transportability in the fire roles were fairly low, near moderately strong (3), but given the ongoing emphasis on the ability to project U.S. military power oversees, it seems more reasonable, and more interesting, to consider the impact of increasing, rather than decreasing, the importance of transportability for systems playing these combat roles. Similarly, the historical role of logistics in land warfare, and the desire to operate in dispersed formations over extended periods of time, make drastic reductions in the importance of self-sufficiency in fire roles fairly implausible, and not particularly interesting. Increasing the importance of stealth in these roles, however, is quite plausible, but its impact in the near term is less substantial than making transportability more important.

**Table 10.13**

**Scenario Preference Frequencies for Medium Versus Heavy in the Near Term, Under Selected System Role Rating Perturbations**

| Perturbation in System Role Importance Ratings | Preference Frequencies in Future Scenarios | | |
|---|---|---|---|
| | (A) Small-Scale Interventions | (B) Balanced Mix of Contingencies | (C) Major Regional Conflicts |
| Moderate to large increase in importance of Transportability in all direct and indirect fire roles | 0.58 → 0.76 | 0.42 → 0.59 | 0.23 → 0.37 |
| Large decrease in importance of Transportability in close air support and deep air interdiction roles | 0.58 → 0.76 | 0.42 → 0.66 | 0.23 → 0.44 |
| Small decrease in importance of Mobility and Protection; small increase for Self-sufficiency and Stealth; in both close air support and deep air interdiction roles | 0.58 → 0.45 | 0.42 → 0.32 | 0.23 → 0.12 |
| Small increase in importance of Mobility and Protection; small decrease for Self-sufficiency and Stealth; in both close air support and deep air interdiction roles | 0.58 → 0.62 | 0.42 → 0.54 | 0.23 → 0.35 |

The first of the two perturbations that affect the air roles was selected based on the same two factors. This perturbation, which makes transportability less important, was more plausible than the other air-role perturbation, which makes self-sufficiency more important, and its impact was more focused on the option pairs under consideration in the two time frames. While air systems usually rate highly on transportability, the degree to which these ratings really contribute to the overall transportability of a force is debatable. Thus, the proper rating for the importance of this characteristic for air roles might be much lower than the high baseline value of very strong (7), even as low as minimal (1). It is much harder, however, to justify raising the importance of self-sufficiency in these roles from moderately strong (3) all to way up to extremely strong (9), since this is usually one of the weaker characteristics of air systems, but is less crucial because they can fly themselves back to a support base well behind the combat area. The impact of decreasing the importance of transportability for air systems is also focused on the relative attractiveness of medium versus heavy in the near term,

and advanced air + SOF versus lean heavy in the far term, whereas increasing the importance of self-sufficiency has more of an effect on the relationship between medium and air + SOF in the near term, and advanced air + SOF and enhanced light in the far term.

**Table 10.14**

**Scenario Preference Frequencies for Advanced Air + SOF Versus Lean Heavy in the Far Term, Under Selected System Role Rating Perturbations**

| Perturbation in System Role Importance Ratings | Preference Frequencies in Future Scenarios | | |
|---|---|---|---|
| | (A) Small-Scale Interventions | (B) Balanced Mix of Contingencies | (C) Major Regional Conflicts |
| Moderate to large increase in importance of Transportability in all direct and indirect fire roles | 0.12 → 0.30 | 0.06 → 0.12 | 0.00 → 0.02 |
| Large decrease in importance of Transportability in close air support and deep air interdiction roles | 0.12 → 0.71 | 0.06 → 0.39 | 0.00 → 0.07 |
| Small decrease in importance of Mobility and Protection; small increase for Self-sufficiency and Stealth; in both close air support and deep air interdiction roles | 0.12 → 0.01 | 0.06 → 0.00 | 0.00 → 0.00 |
| Small increase in importance of Mobility and Protection; small decrease for Self-sufficiency and Stealth; in both close air support and deep air interdiction roles | 0.12 → 0.55 | 0.06 → 0.26 | 0.00 → 0.07 |

As Table 10.13 shows, the scenario preference frequencies for medium versus heavy in the near term were substantially increased by both of the selected large, controversial perturbations. In scenario A, both set of rating changes increased the preference frequency to over 75 percent, in favor of medium, but in scenarios B and C, where mid and high-intensity mission are more important, decreasing the importance of transportability in air roles favored medium slightly more than increasing the importance of this characteristic in the fire roles. In both cases, medium gained enough to be clearly preferred in scenario B, and much more competitive in scenario C. The two combinations of small, influential changes also had a substantial effect on the

scenario preference frequencies in the near term. Reducing the importance of mobility and protection in the air roles, while increasing that of self-sufficiency and stealth in these roles, favored heavy, pushing the preference frequency for medium down by about 0.15 in scenario A, and 0.10 in scenarios B and C, giving heavy the advantage in all three, even scenario A, where low-intensity missions are the most important. The opposite perturbation in these air role ratings—raising the importance of mobility and protection, while lowering that of self-sufficiency and stealth—increased the preference frequency for medium by just 0.04 in scenario A, and by 0.12 in scenarios B and C, which was enough to put medium ahead in scenario B.

In the far term, the scenario preference frequencies for advanced air + SOF versus lean heavy were also affected substantially by these four perturbations, as Table 10.14 clearly shows. The two large, controversial perturbations both favor advanced air + SOF, but the impact of making transportability less important in the air roles was much larger than that of increasing its importance in the fire roles. In scenario A, the former perturbation made advanced air + SOF more strategically valuable than lean heavy over 70 percent of the time, compared to just 12 percent with the baseline ratings, and in scenario B, it pushed the preference frequency up from the baseline value of 6 percent to almost 40. By contrast, increasing the importance of transportability in the fire roles only raised the preference frequency to 30 percent in scenario A, and just 12 in scenario B. The two combinations of small, influential changes again had opposite effects. Making mobility and protection less important in the air roles, while making self-sufficiency and stealth more important, favored lean heavy, pushing the preference frequency for advanced air + SOF down to zero, or very close, in all three scenarios. The opposite perturbations, which made mobility and protection more important, while making self-sufficiency and stealth less important, raised the preference frequency to a 55 percent majority in scenario A, a respectable 26 percent in scenario B, and even 7 percent in scenario C.

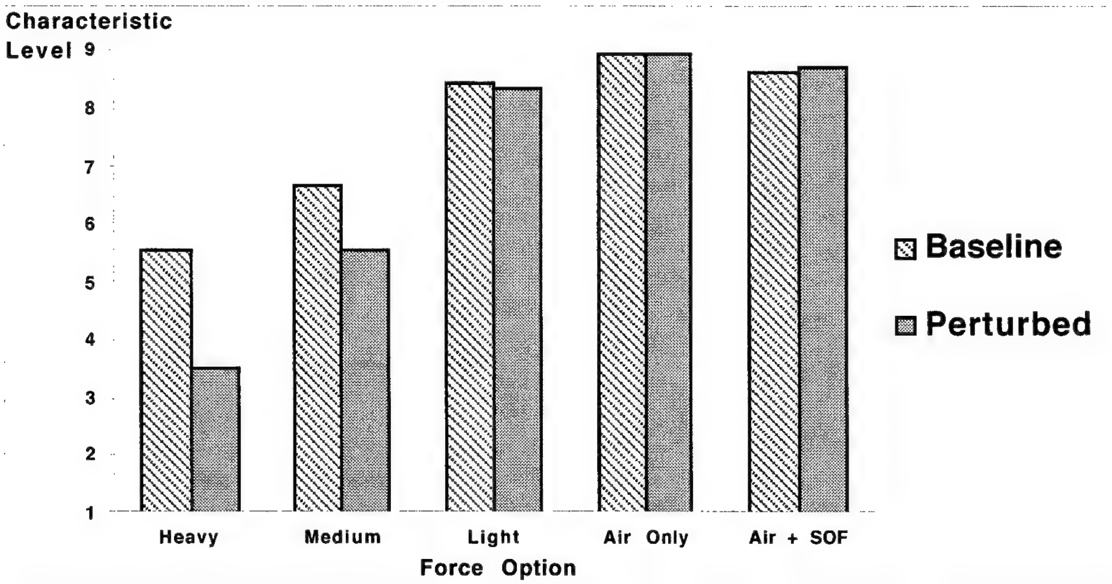



**Figure 10.8. Change in Median Transportability of Near-Term Options due to a Large Decrease in the Importance of Transportability for Close Air Support and Deep Air Interdiction.**

The second of the two large, controversial perturbations is highlighted in both Table 10.13 and Table 10.14, since it had the greatest impact on the scenario preference frequencies in both time frames. This perturbation decreases the importance of transportability in the two air roles, while leaving all of the other system role importance ratings at their baseline values. As a result, systems playing an air role were given less weight in determining the force-level transportability of each force option, and systems playing another role were given more weight. Since air systems generally rate higher on transportability than other systems because they can self-deploy, shifting emphasis away from these roles tends to lower the transportability of force options that include a mix of air and non-air systems. This effect is apparent in Figure 10.8, which shows the baseline transportability levels of the near-term options in comparison to their new levels after this perturbation. The rating changes had little effect on the light, air only, and air + SOF options, but the medium option, and especially the heavy option, experienced a significant reduction in overall transportability. The non-air systems in heavy, and to a lesser extent in medium, are much less transportable than the air systems, so if weight in the force-level transportability

calculation is shifted to them, their lower values bring down the overall level. The same effect is also apparent in Figure 10.9, which shows the impact of this perturbation on the transportability levels of the far-term options. In this case, the enhanced light and advanced air + SOF options are bit less transportable than their near-term counterparts, since they include some new systems that are a bit less transportable. The lean heavy option experiences a large effect because its non-air systems, which compose a large fraction of the force, are not very transportable.

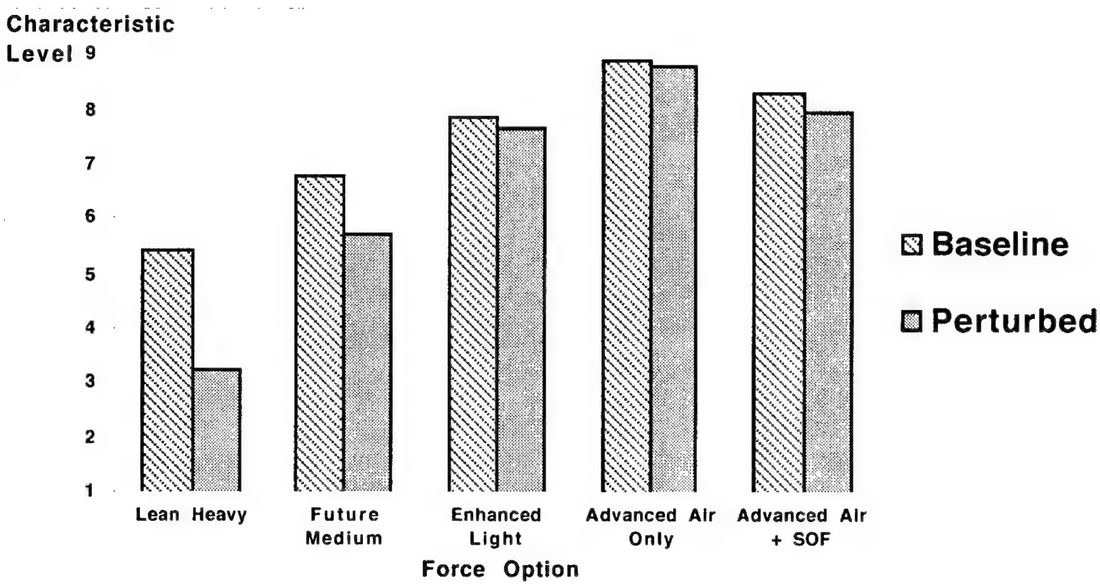


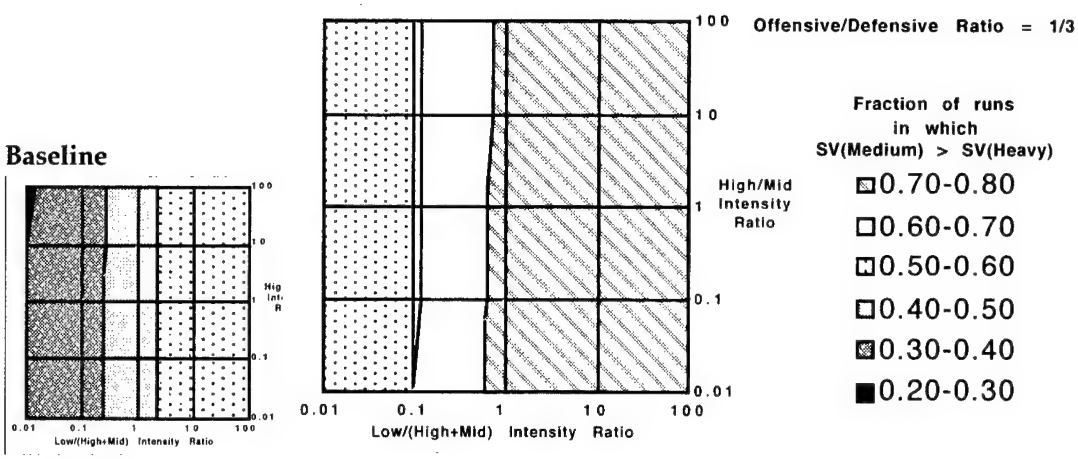

**Figure 10.9. Change in Median Transportability of Far-Term Options due to a Large Decrease in the Importance of Transportability for Close Air Support and Deep Air Interdiction.**

Figure 10.10 shows the impact that this perturbation has on the shape of the preference surface for medium versus heavy in the near term, with the baseline surface plots for each slice inset on the left. These plots show that the shape of the surface, in terms of the contour patterns and the slopes they imply, was not altered very much from the baseline shape. The elevation of the new perturbed surface, however, is consistently at least 0.20 higher everywhere in the space. At every point in the first slice, where defensive missions are three times as important as offensive ones, medium is more strategically valuable than heavy

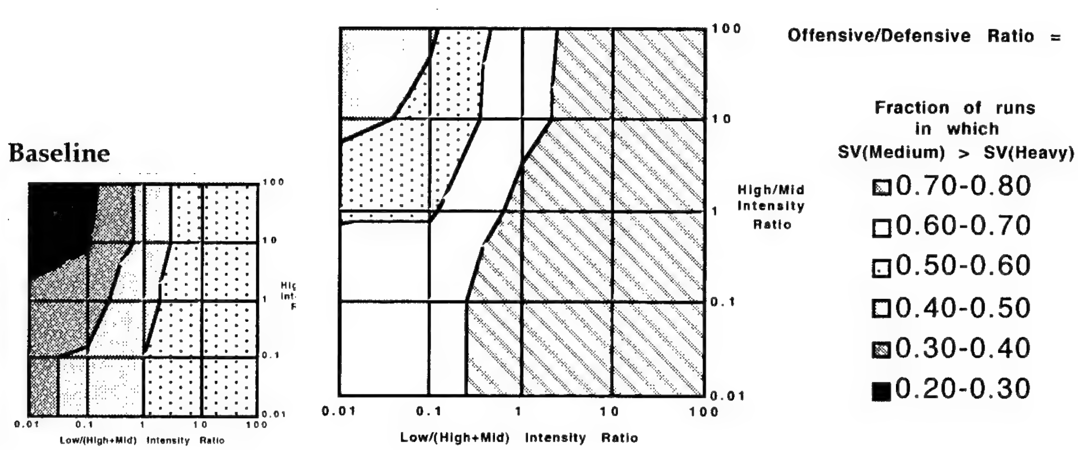
over half the time, and is preferred over 70 percent of the time if low-intensity missions are also more important that other types of missions. As offensive missions become more important, however, heavy is sometimes preferred more often than medium, but only in the upper left corner of the fixed-offensive-to-defensive-ratio slices, where high-intensity missions are much more important than other types of missions. This shape, and the relationships it implies, reflect the first-place frequencies of these options that were discussed earlier: medium placed first more often than heavy in every mission except evict, where heavy dominated, while medium dominated in protect, stabilize and raid.

## 10.2 FORCE OPTION ALTERATION

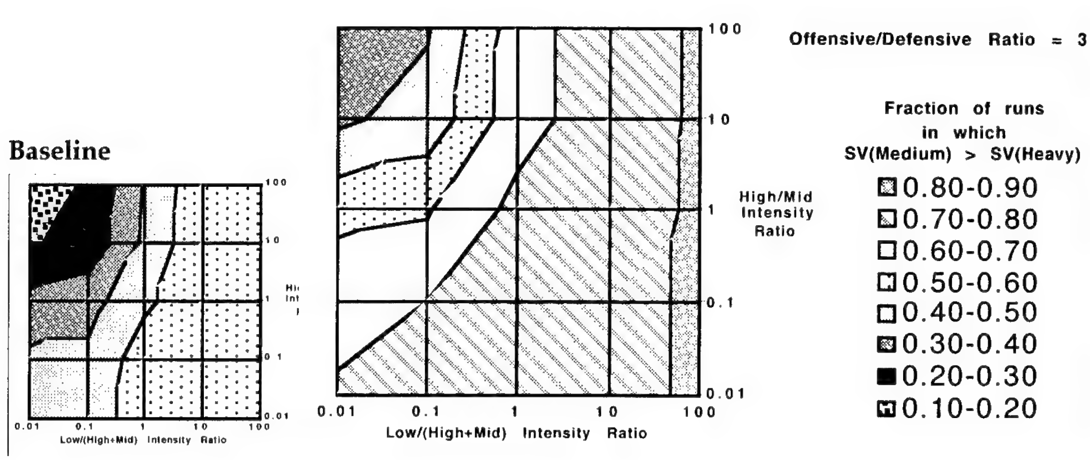
Force options are altered to explore the sensitivity of their effectiveness across missions to changes in composition. An option can be altered by changing (1) the roles its component systems play in the force, (2) the quantity of each type of system included in the force, or (3) the mix of operational concepts that the force employs. Each type of alteration changes a different subset of the inputs that determine an option's characteristics. System role alterations simply assign a new role to one or more of an option's component systems. There are nine different system roles, and many types of component systems, so numerous role changes are possible. Only a small number of these were plausible, however, because of differences in system capabilities and role requirements. For example, it is reasonable to reassign an infantry fighting vehicle from direct fire support to direct fire attack, but not to close air support, since this type of system cannot fly. In fact, only those alterations that switched the assignment of a single individual system type to another role in the same group were considered. The roles in each group generally had similar ratings, so it is not surprising that these alterations had very little impact on the option rankings, never causing more than a handful of rank shifts. Since the effects of these alterations were minimal, and hence uninteresting, their impact results are not presented here.




(a)




(b)




(c)

**Figure 10.10. Preference Surface for Medium over Heavy in Near Term if Transportability is a Lot Less Important in Air Roles, when: (a) defensive missions are more important; (b) offensive and defensive are missions equally important; and (c) offensive missions are more important.**

The results that are presented show the impact of the other two types of force option alterations, which alter the system and operational composition of an option directly. The system composition of an option is altered by changing the numbers of systems of various types that comprise the force. This changes the system quantity weights that are used to aggregate the characteristics of an option's component systems to determine its force-level characteristics values. As an intermediate step in these calculations, the quantity weights are adjusted to account for differences in the importance of each characteristic in the roles assigned to the component systems. This provides a set of importance weights for the contribution of each system to every system characteristic. The analogous weights in the operational characteristic calculations are input directly, so the operational composition of an option is altered by changing these weights, which represent the relative importance of the five operational concepts for an option, or how often it is envisioned to use each of them. Both types of compositional alterations take two forms: systematic shifts involving an individual option component, and sets of specific changes that affect multiple components at once.

To gauge the sensitivity of an option's effectiveness to systematic alterations in its composition, the weight placed on every possible force component is raised by exactly 0.1 , while the weights placed on all the other components are reduced just enough to keep their proportions relative to one another the same. For the system composition alterations, the total number of all systems in the force also remains fixed.[74] These systematic alterations in an option's composition reveal the marginal effect of increasing each of its components, and thus provide an indication of how its mix of systems and operational concepts could be changed to improve its effectiveness. The impact

---

[74] For example, if a force option consisted of 40 As, 30 Bs, and 10 Cs, then a systematic individual alteration that raises the proportion if As in the force by 0.1 would increase its count from 40 to 48, while decreasing the number of Bs from 30 to 24, and the number of Cs from 10 to 8, so that the proportions of A, B and C would go from 0.5, 0.375 and 0.125, to 0.6, 0.3 and 0.1,

results of these systematic alterations provide the rationale for a few plausible sets of specific changes that were considered for each option. Such custom alterations, which may affect multiple components, are intended to represent realistic changes in composition. The following two subsections discuss the results of both systematic and custom alterations in the system and operational composition of the options in each time frame.

### System Composition Alterations

The numbers of different types of systems in a force define its capabilities, which ultimately determine its effectiveness. Thus, altering these quantities can have a substantial impact on the relative standing of an option. Tables 10.15 and 10.16 show the impact of systematic increases in the quantity of each system type in the near-term and far-term options, respectively, in terms of their average differential effect (ADE). The impact of such increases were examined for every system used in each frame, even if they are not a component of the baseline force, but the results for these original component systems are shown in **bold**. The systematic alterations in the air systems that are highlighted in these two tables were very influential for every option, so all of the selected custom alterations involved these systems. These changes were chosen not just for their potential impact, but also because the systems involved are components of almost every option, which makes comparing their effects more meaningful. In the near term, the custom alterations involve three systems: A-10, TAC-AIR and NTACMS. In the far term, they affect four systems: AH-64D+, RAH-66, Advanced TAC-AIR, and Advanced NTACMS. The custom alterations selected for each time frame are shown in Table 10.17, along with their impact on the rankings of the affected options.[75] A custom alteration was selected for every option in the near term,

---

respectively. Such shifts may, of course, result in non-integer numbers of systems, but this is not a problem because these alterations are merely intended to estimate marginal effectiveness.

[75] Since these alterations only affect one option at a time, the largest number of rank shifts for a given mission is always associated with the altered option, and are usually all in its favor.

but only for three of the five options in the far term. Similar alterations were considered for future medium and advanced air only—the best and worst options, respectively, in this time frame—but are not presented here because they had little or no impact on the option rankings. The results of both systematic and custom alterations in the system composition of each option are discussed separately below.

**Table 10.15**

**Impact of Systematic Increases in the Proportion of Each System Type in Near-Term Force Options**

| System Design | Average Differential Effect (x1000) of a 10 Percent Increase in System Proportion | | | | |
|---|---|---|---|---|---|
| | Heavy | Medium | Light | Air Only | Air + SOF |
| M1A2 | **-11** | -3 | 11 | 34 | 40 |
| M2A3/M3A3 | **-19** | -16 | -5 | 13 | 11 |
| M2A3-FGM | **-21** | -23 | -18 | -8 | -8 |
| M109A6 | **-40** | -40 | -33 | -25 | -25 |
| MLRS | **-23** | -25 | -20 | -12 | -13 |
| LAV-DFV | 6 | **4** | 19 | 27 | 27 |
| LAV-IFV | 2 | **-3** | 9 | 19 | 16 |
| LAV-APC | -21 | **-25** | -8 | -1 | -10 |
| LAV-MOR | -7 | **-9** | -5 | 1 | -1 |
| LAV-HOW | -10 | **-14** | -9 | -2 | -5 |
| LAV-FGM | 5 | **0** | 3 | 9 | 9 |
| LAV-REC | 17 | **-4** | -2 | 11 | -10 |
| HIMARS | -9 | **-9** | -6 | -7 | -9 |
| HMMWV-TOW | 5 | -6 | **13** | 13 | 7 |
| Javelin team | **-46** | **-52** | **-44** | -31 | -45 |
| Mortar team | -19 | -28 | **-24** | -17 | -26 |
| HMMWV-HOW | -3 | -11 | **-4** | -8 | -12 |
| HMMWV-FGM | 10 | -4 | **4** | 0 | -2 |
| AH-64D | **-4** | **-12** | **-5** | -23 | **-9** |
| A-10 | **43** | **35** | **38** | 21 | **45** |
| TAC-AIR | **29** | **20** | **21** | **-13** | **20** |
| NTACMS | **40** | **26** | **28** | **13** | **20** |
| SOF-RST | -16 | -49 | -40 | -6 | **-74** |

NOTE: Results in **bold** are for systems that are already components of the force option.

*Near Term*

*Heavy.* All of the land-based systems in the heavy option have large negative ADE values, especially the dismounted Javelin team and the Paladin

self-propelled howitzer (SPH), while the air systems, with the exception of the AH-64D Apache attack helicopter, all have large positive values. This implies that increasing the ratio of air to ground systems in this option would increase its effectiveness, and could improve its standing relative to medium. The custom alteration for heavy tests this hypothesis by doubling the number of air systems. The resulting impact, an average of over 30 rank shifts per mission, is quite substantial. These shifts mostly move heavy from second to first place, adding just 12 first-place spots in the evict mission, but between about 30 and 40 in the other five missions. Together these changes give heavy a large lead over medium in every mission, enabling it to win more than 95 percent of the time in the evict, halt and defend missions, and between 70 and 85 percent of the time in the remaining three missions, protect, stabilize and raid—medium's best.

*Medium.* The systematic alteration results for the medium option were similar to those for heavy, but were generally not as extreme. These alterations had a negative impact for all of the land systems, except the direct fire vehicle (DFV) version of the LAV. These effects were small for most of these systems, but the armored personnel carrier (APC) version of the LAV and the Javelin team were exceptions, with quite large negative ADE values, primarily because of their low levels of protection and mobility or firepower. The results imply that adding more air systems, other than the AH-64D, would make the medium option more effective, and should enable it to make significant gains on the baseline heavy option. Indeed, the custom alteration for medium raises its numbers of air systems up to the same levels as the custom-altered heavy option, by doubling its contingent of A-10 and TAC-AIR aircraft, and tripling its NTACMS launchers. This alteration had about the same impact as its heavy counterpart, with an average of 32.5 rank shifts per mission, most of which moved medium up from second to first place, displacing heavy. These shifts ranged in size from 26 to a high of 38, and gave medium a clear lead in every mission except evict, where heavy still won a slim majority. Medium won

around 80 percent of the time in its three best missions, protect, stabilize and raid, over 65 percent in halt and defend, and even over 40 percent in evict.

*Light*. The light option, like the other ground-based options, heavy and medium, would also benefit from having more air systems, but the systematic alteration results for its land systems are more mixed. The light force would be more effective if had fewer dismounted Javelin and mortar teams, and more TOW and FGM variants of the HMMWV—i.e., it was more mechanized. In fact, if appropriate, the light option might be even better off with a few direct fire and infantry versions of the LAV as well. The custom alteration in the light option increases its complement of air systems up to the same levels as the baseline heavy option: 26 A-10 and 24 TAC-AIR, a full AEF, plus 18 NTACMS. This alteration led to an average of only 8.5 rank shifts per mission, which enabled light to strengthen its hold on fourth place a bit, and pick up a few third-place spots, but not enough to make much of a difference in its overall standing.

*Air Only*. The air only option would be more effective if it had a somewhat different mix of air systems, with fewer TAC-AIR and more NTACMS, and a few more A-10. Accordingly, the custom alteration for this option reduced TAC-AIR and added A-10 and NTACMS to achieve the same total numbers as the altered medium and heavy options. This alteration, however, had only a modest impact, causing an average of just over 9 rank shifts per mission. These shifts, 10 or more in some missions, all moved air only from fifth to fourth place, and gave it totals of about 30 fourth place spots in the halt, defend and raid missions, and over 40 in evict, but just 15 or 16 in protect and stabilize.

*Air + SOF*. Like all of the ground-based options, air + SOF option would benefit from having more air systems. The baseline air + SOF option has the same number of air systems as the heavy option, so the custom alteration for this option, like its heavy counterpart, doubled these numbers. The impact of this alteration was a little bit larger that that of the light and air only alterations, with an average of 15 rank shifts per mission. These shifts gave air + SOF several

more first and second place spots, but since it had very few if any spots in these positions to start with, these gains were not decisive in any mission, with the totals never exceeding 20. Interestingly, the systematic alteration results indicate that this option would be more effective if it had fewer SOF-RST teams. This outcome, which is caused by the poor mobility, protection and firepower of these teams, is misleading. The SOF-RST teams provide the ground presence that enables this option to use the standoff (w/ ground information) operational concept instead of its inferior alternative, standoff (no ground information).

**Table 10.16**

**Impact of Systematic Increases in the Proportion of Each System Type in Far-Term Force Options**

| System Design | Average Differential Effect (x1000) of a 10 Percent Increase in System Proportion | | | | |
|---|---|---|---|---|---|
| | Lean Heavy | Future Medium | Enhanced Light | Advanced Air Only | Advanced Air + SOF |
| M1A3 | **-4** | -19 | 19 | 27 | 41 |
| M2A4 | **-14** | -27 | -1 | 10 | 18 |
| M2A4-FGM | **-14** | -26 | -10 | -4 | 2 |
| Crusader | **-34** | -44 | -31 | -16 | -12 |
| MLRS | **-11** | -18 | -7 | -2 | 2 |
| FSCS | **11** | -17 | -5 | 6 | 3 |
| FCS-DFV | 30 | **14** | 50 | 51 | 66 |
| FCS-IFV | 29 | **12** | 41 | 46 | 56 |
| FCS-APC | 8 | **-10** | 21 | 23 | 32 |
| FCS-ART | 18 | **3** | 23 | 25 | 32 |
| FCS-REC | 31 | **1** | 18 | 26 | 23 |
| ARES | -1 | **-12** | 7 | -4 | 3 |
| Adv. MLRS | 7 | **1** | 13 | 9 | 15 |
| AHMV-FOT | 17 | 2 | **37** | 26 | 36 |
| AHMV-APC | -1 | -14 | **16** | 7 | 17 |
| RST-V | 37 | 9 | **28** | 19 | 18 |
| Adv. Javelin | -41 | -52 | **-34** | -33 | -29 |
| Adv. Mortar | -21 | -31 | **-20** | -20 | -18 |
| Small AFSS | -25 | -34 | **-27** | -22 | **-25** |
| Large AFSS | -20 | -26 | **-21** | -15 | **-16** |
| AH-64D+ | **-13** | **-26** | 2 | -21 | **-2** |
| RAH-66 | **7** | **-16** | **5** | **1** | **8** |
| Adv. TAC-AIR | **18** | **-4** | **27** | **-6** | **27** |
| Adv. NTACMS | **25** | **8** | **32** | **7** | **23** |
| SOF-RST | -11 | -42 | -38 | -15 | **-38** |
| SOF-AST | 12 | -19 | -17 | 8 | **-12** |

NOTE: Results in **bold** are for systems that are already components of the force option.

**Table 10.17**

**Impact of Changes in System Composition of Options on Rankings**

| *Option* Changes in System Composition | Average Rank Shifts per Mission |
|---|---|
| **NEAR TERM** | |
| *Heavy*<br>A-10: 26 → 52<br>TAC-AIR: 24 → 48<br>NTACMS: 18 → 36 | 30.83 |
| *Medium*<br>A-10: 26 → 52<br>TAC-AIR: 24 → 48<br>NTACMS: 12 → 36 | 32.50 |
| *Light*<br>A-10: 12 → 26<br>TAC-AIR: 10 → 24<br>NTACMS: 6 → 18 | 8.50 |
| *Air Only*<br>A-10: 0 → 52<br>TAC-AIR: 72 → 48<br>NTACMS: 18 → 36 | 9.33 |
| *Air + SOF*<br>A-10: 26 → 52<br>TAC-AIR: 24 → 48<br>NTACMS: 18 → 36 | 15.00 |
| **FAR TERM** | |
| *Lean Heavy*<br>RAH-66: 9 → 18<br>Adv. TAC-AIR: 72 → 100<br>Adv. NTACMS: 18 → 36 | 5.33 |
| *Enhanced Light*<br>AH-64D+: 0 → 9<br>RAH-66: 9 → 18<br>Adv. TAC-AIR: 16 → 36<br>Adv. NTACMS: 6 → 18 | 21.83 |
| *Advanced Air + SOF*<br>AH-64D+: 18 → 9<br>RAH-66: 9 → 18<br>Adv. TAC-AIR: 72 → 100<br>Adv. NTACMS: 18 → 36 | 14.33 |

*Far Term*

*Lean Heavy*. Systematic increases in the land systems of the lean heavy option generally had a negative impact on its effectiveness. The one exception was the FSCS, which had a modest, but significant positive impact. Also, the

negative impact of the M1A3, a notional future upgraded version of the Abrams main battle tank, was quite small. The Crusader SPH system, however, had a relatively large negative impact, since it has a very low level of transportability. The systematic alteration results also indicate that replacing some of heavy's land systems with lighter vehicles like the FSC variants would make this option more effective, which is not that surprising since the FCS-based future medium option is clearly the best far-term option. It is also interesting to note that adding some RST-V systems to heavy had a substantial positive impact. With regard to air systems, the systematic alteration results show that adding more advanced TAC-AIR aircraft, advanced NTACMS missile launchers, or RAH-66 reconnaissance-attack helicopters, made lean heavy more effective. But, adding more AH-64D+ helicopters, a notional future version of the Apache Longbow, had a moderate negative effect. The custom alteration for lean heavy doubled the number of RAH-66 and Advanced NTACMS, and increased the number of Advanced TAC-AIR to 100. This alteration, which caused an average of just over 5 rank shifts per mission, strengthened heavy's already firm hold on second place in the far term, raising its frequency to around 90 percent in the low-intensity missions, and to 99 or 100 percent in the other four missions.

*Future Medium.* The results of the systematic alterations in the system quantities of the future medium option are quite interesting, but not very relevant, since this option is well ahead of the others in the far term. These results indicate that the future medium option would be even more effective if it had more DFV and IFV variants of the FCS, and fewer APC versions. They also show that it would benefit from more advanced NTACMS missile launchers at sea, and fewer robotic ARES missile launchers on land. In addition, the fairly large negative ADE values for increases in the number of AH-64D+ and RAH-66 helicopters indicate that future medium would be more effective with fewer of these systems. Only one system that is not already in this force, the RST-V, a small light-weight reconnaissance vehicle, made this option more effective when it was added to the force. Of course, various combinations of the beneficial

changes discussed above would make this option—which is already always the best—even better, so they do not have any effect on the option rankings.

*Enhanced Light*. The systematic alterations for the enhanced light option indicated that it would be more effective if it had fewer advanced Javelin and mortar teams, and fewer of both the small and large versions of the remotely-controlled AFSS missiles-in-a-box systems. This option would, however, benefit quite a bit from having more AHMV systems, especially the FOT version, and more RST-V vehicles as well. With regard to air systems, enhanced light gained the most from having more advanced TAC-AIR aircraft, and more advanced NTACMS missile launchers. Adding more AH-64D+ and RAH-66 helicopters also had a small, but positive impact, with the RAH-66 contributing a bit more. The custom alteration for enhanced light reflected these air system results, adding 9 AH-64D+ helicopters, 9 RAH-66 helicopters, 12 advanced NTACMS launchers, and 20 advanced TAC-AIR aircraft. This set of changes led to an average of nearly 22 rank shifts per mission. Enhanced light gained about 10 second-place spots in the low-intensity missions, elevating its totals to between 10 and 15. It also gained less than 10 third-place spots in these two missions, and 20 or more in other four, to reach totals ranging from about 30 to 40 in every mission. While these shifts raised enhanced light's standing in third place, they still left advanced air + SOF ahead in every mission, although they brought it quite close in protect, stabilize and raid.

*Advanced Air Only*. The systematic alteration results for the advanced air only option indicate that the proportions of this option are about right, although it could use a few more advanced NTACMS and a few less advanced TAC-AIR. This option was also well behind the others in every mission, so all of the custom alterations considered for it had only a minimal effect on the option rankings.

*Advanced Air + SOF*. The systematic alteration results for advanced air + SOF option indicate that it would be more effective if it had more TAC-AIR aircraft, more advanced NTACMS missile systems, and even a few more RAH-66

helicopters as well. Moreover, these results suggest that it would be better off with fewer of all its other land-based systems: the small and large AFSS remote missile systems, and the two types of SOF teams, especially the RST version, primarily because these systems all have very poor mobility and protection. The custom alteration for the advanced air + SOF option makes the same changes in the RAH-66, advanced TAC-AIR and advanced NTACMS totals as the heavy alteration, since both of these forces have the same initial numbers of these systems, while also cutting the number of AH-64D+ helicopters in half. This alteration caused an average of just over 14 rank shifts per mission, most of which moved this option from third to second place. Advanced air + SOF gained over 20 spots in the low-intensity missions to reach totals of 33 to 35, but only picked up 11 or fewer in the other missions, for totals of less than 20—not enough to surpass lean heavy in any mission.

## Operational Composition Alterations

The mix of operational concepts that an option employs determines its effectiveness, since its overall operational characteristics are derived from those of its component concepts, in proportion to how often it uses them. Tables 10.18 and 10.19 show the impact of systematic increases in the importance proportion assigned to each operational concept in the near-term and far-term force options, respectively. The impact results for these systematic alterations, in terms of its ADE, are shown in **bold** if the baseline version of the option includes the concept that is being used more. Positive ADE values indicate that using that concept more would improve the option's effectiveness relative to other options, while negative values indicate that using it more would lower its relative effectiveness. Thus, these results suggest which operational concepts in each option should receive more weight, and which should be receive less, in order to increase its standing relative to the other options. Based on these indications, a few custom alterations that make specific changes in the concept weights were considered for each option, in both time frames. Of course, various factors constrain the extent

to which an option can use certain concepts. For example, it is difficult for an air only force to use maneuver warfare to any great extent. Such limitations are pushed to their limits in the custom alterations selected for each option, which are shown in Table 10.20 along with the impact they had on that option's rankings. The systematic alteration results in Tables 10.18 and 10.19 are highlighted to indicate which of the operational concepts are affected by the custom alterations. As with the system alterations, a set of custom changes was selected for each option in the near term, but only for three of the five options in the far term, since, for the same reasons, the custom alterations considered for the future medium and advanced air only options had little or no impact on these options' rankings. The results of the systematic and custom alterations in the operational concept mix used by each option are discussed separately below.

**Table 10.18**

**Impact of Systematic Increases in the Proportion of Each Operational Concept Used in the Near-Term Force Options**

| | Average Differential Effect (x1000) of a 10 Percent Increase in System Proportion | | | | |
|---|---|---|---|---|---|
| **Operational Concept** | Heavy | Medium | Light | Air Only | Air + SOF |
| Standoff (no ground info) | -85 | -78 | -46 | **0** | -56 |
| Standoff (w/ ground info) | **-25** | **-27** | **11** | 49 | **0** |
| Maneuver Warfare | **17** | **12** | 34 | 73 | 27 |
| Ambush/Envelopment | **30** | **42** | 51 | 88 | 45 |
| Peace Keeping/Enforcement | **-41** | **-37** | **-11** | 39 | -12 |

NOTE: Results in **bold** are for operational concepts that are already used by the force option.

*Near Term*

*Heavy*. The systematic alterations for the heavy option indicate that its effectiveness relative to the other options would be improved if it used ambush/ envelopment and maneuver warfare more often, and used standoff (w/ ground info) and peace keeping/enforcement less often. In following with these results, the custom alteration for heavy eliminated these standoff and peace operational concepts altogether, shifting most of this weight to the maneuver warfare concept, giving it a total of 80 percent, and assigned the remaining 20 percent to

ambush/envelopment. Ideally, ambush/envelopment should receive an even larger fraction of the total weight, because the impact of its individual alteration was larger than of maneuver warfare. But, since the heavy force's organization and capabilities are best suited for maneuver warfare, the scope of its ability to employ ambush/envelopment is likely to be fairly narrow, so using this other concept one fifth of the time, as opposed to one seventh in the baseline case, is quite reasonable. This custom alteration causes an average of over 37 rank shifts per mission, a substantial impact. Specifically, it shifts enough additional first-place spots to heavy for it to win over 90 percent of the time in every mission.

*Medium.* The systematic alteration results for medium are quite similar to heavy's, indicating that the standoff and peace concepts should be reduced in favor of more emphasis on ambush/envelopment and, to a somewhat lesser extent, maneuver warfare. The nature and capabilities of the medium force make it more conducive to the use of the ambush/envelopment concept than the heavy option. In particular, its lighter systems and streamlined organization give it more flexibility and greater operationally agility. These advantageous features of the medium option also incur some penalties, however, in that it cannot entirely abandon the standoff and peace concepts. These constraints are reflected in the distribution of operational concept weights in the custom alteration for medium. This alteration raises the weight placed on maneuver warfare from one seventh to one fifth, and that placed on ambush/envelopment from one third to one half. At the same time, it only reduces the weight placed on standoff (w/ ground info) from one third to one fifth, and that placed on peace keeping/enforcement from one seventh to one tenth. Together, these fairly modest shifts in emphasis had a large impact, causing an average of over 50 rank shifts per mission. Most of these were large shifts that moved medium from second to first place, enabling it to surpass heavy in every mission, winning around 70 percent of the time even in evict, over 80 in defend, and over 90 in all the other missions.

*Light*. The results of the systematic alterations in the concept proportions of the light option were quite interesting. They indicated that this option would be improved somewhat if the ratio between its two operational components in the baseline case was shifted in favor of standoff (w/ ground info) over peace keeping/enforcement. In addition, this option would benefit from using maneuver warfare and ambush/envelopment to some degree, although the poor mobility and protection of this force limit the extent to which it can employ these concepts effectively. Accordingly, the custom alteration for light assigns weights of just one tenth each to these two concepts, and splits the remaining 80 percent equally between the standoff and peace concepts. The impact of this custom alteration was quite a bit smaller than those of the heavy and medium options, but still substantial, with an average of 22 rank shifts per mission. Light made gains of near 20 or more third-place spots in the halt, protect, raid and stabilize missions, but these shifts were not decisive because light had few if any of these spots in the baseline evaluation.

*Air Only*. The systematic alteration results for the air only option have a clear message: shifting weight away from standoff (no ground info) to any of the other concepts would lead to some improvement. These results indicate that employing the maneuver warfare or ambush/envelopment concepts would add the most to this option, although these concepts would be very difficult for this type of force to employ, since it has no ground presence. Standoff (w/ ground info) is a more plausible alternative concept for this option, provided that it can obtain reliable ground information from aerial or ground sensors. This option can also employ the peace keeping/enforcement concept in some circumstances, like no-fly zones or in conjunction with allied peacekeeping forces on the ground. These limitations are reflected in the custom alteration for the air only option, which assigns one fifth of the total weight to standoff (w/ ground info), one tenth to peace keeping/enforcement, and one twentieth each to maneuver warfare and ambush/envelopment, leaving just 60 percent for standoff (no ground info), the only component concept in the baseline case. This alteration

had a significant impact on the standing of this option, leading to an average of over 40 rank shifts per mission. Air only had a majority of the fifth-place spots in the baseline evaluation, but picked up about 30 fourth-place spots, mostly from light, and even about 10 third-place spots too, in every mission. These shifts gave air only the lead for fourth place in all of the non-low-intensity missions, with over 50 percent of all these spots. In the two low-intensity missions, however, it ended up with less than 40 percent, so light still had the advantage.

*Air + SOF*. The systematic alterations for air + SOF indicate that it would benefit from using maneuver warfare or ambush/envelopment, rather than relying exclusively on standoff (w/ ground info), as it does in the baseline case. Given this option's air-orientation, it is difficult for it to employ either of these concepts, especially maneuver warfare. The ground presence provided by the SOF-RST teams in this option could, however, enable it to employ a form of ambush/envelopment in which these teams would lure enemy forces into an exposed position and then coordinate with aircraft and long-range missile systems to surprise them with concentrated, preplanned air attacks. With this rationale in mind, the custom alteration for air + SOF assigned a weight of 0.3 to ambush/envelopment, and just 0.1 to maneuver warfare, leaving 0.6 for standoff (w/ground information). This alteration had a very large impact, causing 65 rank shifts per mission, many of which displaced either heavy or medium from first or second place. Air + SOF gained over 50 first-place spots in the low-intensity missions to achieve totals of over 60. It also picked up over 40 first-place spots in the other non-evict missions to reach totals of around 50, giving it a clear lead in raid, a small lead in halt, and tie for the lead in defend. In evict, however, air only still ended up well behind heavy with 24 first-place spots.

## Table 10.19

### Impact of Systematic Increases in the Proportion of Each Operational Concept Used in the Far-Term Force Options

| Operational Concept | Average Differential Effect (x1000) of a 10 Percent Increase in System Proportion | | | | |
|---|---|---|---|---|---|
| | Lean Heavy | Future Medium | Enhanced Light | Advanced Air Only | Advanced Air + SOF |
| Standoff (no ground info) | -40 | -39 | -35 | **0** | -33 |
| Standoff (w/ ground info) | **-15** | **-17** | **-11** | 25 | **-25** |
| Maneuver Warfare | **4** | **2** | 7 | 37 | 7 |
| Ambush/Envelopment | 17 | **18** | **25** | 48 | **25** |
| Peace Keeping/Enforcement | **-10** | **-9** | **-7** | 28 | -3 |

NOTE: Results in **bold** are for operational concepts that are already used by the force option.

*Far Term*

*Lean Heavy*. The impact results for systematic alterations in the mix of operational concepts used by the lean heavy option indicated that its standing relative to the other options would improve if it used the ambush/envelopment concept more often, while reducing its reliance on the standoff and peace concepts. (While these operational concepts have the same names as their near term counterparts, they do not necessarily have the same operational characteristics.) The custom alteration for lean heavy eliminates its use of standoff (w/ ground info) and peace keeping/enforcement, and pushes the limits of this option's capabilities by assigning fully three-quarters of all the weight to ambush/envelopment, leaving only a quarter for maneuver warfare, the traditional concept used by this type of force. The modest overall impact of this alteration, with an average of 18.5 rank shifts, belies its significance. This alteration is extremely interesting because it actually breaks the seemingly unassailable hold that future medium had on first place in the baseline evaluation. Under this aggressive realignment of the operation concept mix, lean heavy wins 39 first-place spots in the evict mission, 16 each in halt and defend, and even picks up 4 in protect. In the process, it also picks up the all of the baseline second-place spots held by advanced air + SOF or enhanced light.

**Table 10.20**

**Impact of Changes in Operational Composition of Options on Their Rankings**

| *Option* Changes in Operational Composition | Average Rank Shifts per Mission |
|---|---|
| **NEAR TERM** | |
| *Heavy*<br>Standoff (w/ ground info): 0.143 → 0.0<br>Maneuver Warfare: 0.571 → 0.8<br>Ambush/Envelopment: 0.143 → 0.2<br>Peace Keeping/Enforcement: 0.143 → 0.0 | 37.17 |
| *Medium*<br>Standoff (w/ ground info): 0.333 → 0.2<br>Maneuver Warfare: 0.167 → 0.2<br>Ambush/Envelopment: 0.333 → 0.5<br>Peace Keeping/Enforcement: 0.167 → 0.1 | 51.00 |
| *Light*<br>Standoff (w/ ground info): 0.333 → 0.4<br>Maneuver Warfare: 0.000 → 0.1<br>Ambush/Envelopment: 0.000 → 0.1<br>Peace Keeping/Enforcement: 0.667 → 0.4 | 22.00 |
| *Air Only*<br>Standoff (no ground info): 1 → 0.60<br>Standoff (w/ ground info): 0 → 0.20<br>Maneuver Warfare: 0 → 0.05<br>Ambush/Envelopment: 0 → 0.05<br>Peace Keeping/Enforcement: 0 → 0.10 | 41.33 |
| *Air + SOF*<br>Standoff (w/ ground info): 1 → 0.6<br>Maneuver Warfare: 0 → 0.1<br>Ambush/Envelopment: 0 → 0.3 | 65.00 |
| **FAR TERM** | |
| *Lean Heavy*<br>Standoff (w/ ground info): 0.143 → 0.00<br>Maneuver Warfare: 0.571 → 0.25<br>Ambush/Envelopment: 0.143 → 0.75<br>Peace Keeping/Enforcement: 0.143 → 0.00 | 18.50 |
| *Enhanced Light*<br>Standoff (w/ ground info): 0.30 → 0.10<br>Maneuver Warfare: 0.00 → 0.10<br>Ambush/Envelopment: 0.20 → 0.60<br>Peace Keeping/Enforcement: 0.50 → 0.20 | 71.33 |
| *Advanced Air + SOF*<br>Standoff (w/ ground info): 0.75 → 0.40<br>Maneuver Warfare: 0.00 → 0.10<br>Ambush/Envelopment: 0.25 → 0.50 | 35.50 |

*Future Medium.* The systematic alteration results for future medium are almost identical to those for lean heavy; using the standoff and peace concepts

less often, and the ambush/envelopment concept more often, would improve its effectiveness relative to the other option. But, since this option is solidly ahead of the other options in every mission, the application of alterations based on these results did not affect the option rankings in any way.

*Enhanced Light.* The systematic alteration results for enhanced light indicate that this option would fare better if it used the standoff and peace concepts a bit less, and used the ambush/envelopment concept more instead. The custom alteration for enhanced light follows these suggestions with fairly aggressive shifts in the operational concept weights: standoff (w/ ground info) and peace keeping/enforcement were reduced to weights of 0.1 and 0.2, respectively, while the weight placed on ambush/envelopment was tripled to 0.6, and 0.1 was assigned to maneuver warfare. This alteration had a very large impact, causing an average of over 70 rank shifts per mission, which pushed enhanced light ahead of advanced air + SOF in every mission. Enhanced light gained nearly 70 or more second-place spots for a clear lead in the two low-intensity missions, and 20 to 30 spots in the other missions, except evict, where lean heavy kept a strong lead. It also picked up enough third-place spots to dominate this position in all the non-low-intensity missions, with totals between 60 and 70.

*Advanced Air Only.* The systematic alteration results for the advanced air only option indicate that, just as was the case with its near-term counterpart, this option would benefit from using any of the other operational concepts, especially ambush/envelopment or maneuver warfare, although these concepts would remain difficult for it to employ. Since this option is so far behind the others in the baseline evaluation, however, all of the plausible custom alterations that shifted some fraction of the total weight to these other concepts caused only about 5 to 10 rank shifts, and were never decisive, so none of them were selected.

*Advanced Air + SOF.* The systematic alteration results for the advanced air + SOF option suggest that increasing its weight on ambush/envelopment, while decreasing its weight on standoff (w/ ground info), and at the same time adding

a bit of weight on maneuver warfare, would improve the relative standing of this option. The custom alteration for this option followed this advice, lowering the standoff (w/ ground info) weight to just 0.4, while raising the weight on ambush/envelopment to 0.5, and assigning the remaining 0.1 to maneuver warfare. This alteration had a significant impact, with an average of over 35 rank shifts per mission. Most of these shifts moved Advanced air + SOF from third to second place, displacing lean heavy from this position. The largest gains were in the two low-intensity missions, protect and stabilize, where advanced air + SOF picked up about 60 spots to win a total of 72 percent of the time in both missions. Lean heavy maintained the lead in the other four missions, although advanced air + SOF, which had only a handful if any spots in the baseline case, gained nearly 40 spots in raid, 30 in halt and 20 in defend, but only one in evict.

### Impact of Selected Alterations on Option Preferences

Only those custom alterations that involve one of the options that are compared in each time frame—medium versus heavy in the near term, and advanced air + SOF versus lean heavy in the far term—are examined here. The selected changes in the system and operational composition of these four options, and their overall impact, are highlighted in Tables 10.17 and 10.20. These alterations influence the effectiveness of the altered option relative to other options, but do not affect the standing of the others relative to one another. The impact of the medium and heavy alterations in the near-term are shown in Table 10.21, in terms of the shifts they cause in the preference frequency for medium. The corresponding impact results for the alterations in the advanced air + SOF and lean heavy options in the far term are shown in Table 10.22.

#### *Near Term*

The first of the near-term alterations increases the size of the air and missile contingent of the heavy option, doubling the number of A-10, TAC-AIR and NTACMS systems in the force, while leaving all of the other system quantities

unchanged. This alteration increases the ratio of air to land systems, which favors heavy because the air systems are more transportable and stealthy than the land systems in this force. Figure 10.11 shows the effects that this alteration had on the force-level system characteristic values for heavy. The largest increases were, in fact, in transportability and stealth. Mobility and firepower also went up slightly, while protection and self-sufficiency went down a bit. The impact of these effects is apparent in the preference frequency shifts for this alteration, which are highlighted in Table 10.21. Medium lost ground to heavy in all three scenarios, dropping to just 17 percent in scenario A, which it led in the baseline with 58 percent, a paltry 6 percent in scenario B, and only 1 percent in scenario C.

**Table 10.21**

**Scenario Preference Frequencies for Medium Versus Heavy in the Near Term, Under Selected Alterations in Option Composition**

| *Option Altered* / **Alteration in Composition** | **Preference Frequencies in Future Scenarios** | | |
|---|---|---|---|
| | (A) Small-Scale Interventions | (B) Balanced Mix of Contingencies | (C) Major Regional Conflicts |
| *Heavy*<br>Double aircraft (A-10 and TAC-AIR) from 1 to 2 full AEF-equivalents, and double naval missile launchers | 0.58 → 0.17 | 0.42 → 0.06 | 0.23 → 0.01 |
| *Medium*<br>Double aircraft (A-10 and TAC-AIR) from 1 to 2 full AEF-equivalents, and triple naval missile launchers | 0.58 → 0.79 | 0.42 → 0.75 | 0.23 → 0.58 |
| *Heavy*<br>Eliminate use of standoff and peace keeping/enforcement concepts, focus on maneuver warfare and ambush/envelopment in ratio of 4-to-1 | 0.58 → 0.08 | 0.42 → 0.04 | 0.23 → 0.01 |
| *Medium*<br>Use ambush/envelopment most (5), peace keeping/ enforcement least (1), and standoff and maneuver warfare in between and about equally (2) | 0.58 → 0.98 | 0.42 → 0.92 | 0.23 → 0.79 |

The second alteration involves almost exactly the same set of changes in the numbers of air systems in the medium force; the A-10 and TAC-AIR totals are

doubled from the same initial levels, and the NTACMS are tripled to end up with the same new total as the altered heavy option. While the land systems in the medium force are more transportable than those in the heavy option, they are still not rated as highly as the air systems, so medium also experienced similar benefits from having more of them. Indeed, this alteration raised the preference frequencies in favor of medium, giving it a solid lead in all three scenarios, with nearly 80 percent in scenario A, 75 percent in scenario B, and almost 60 percent even in scenario C.

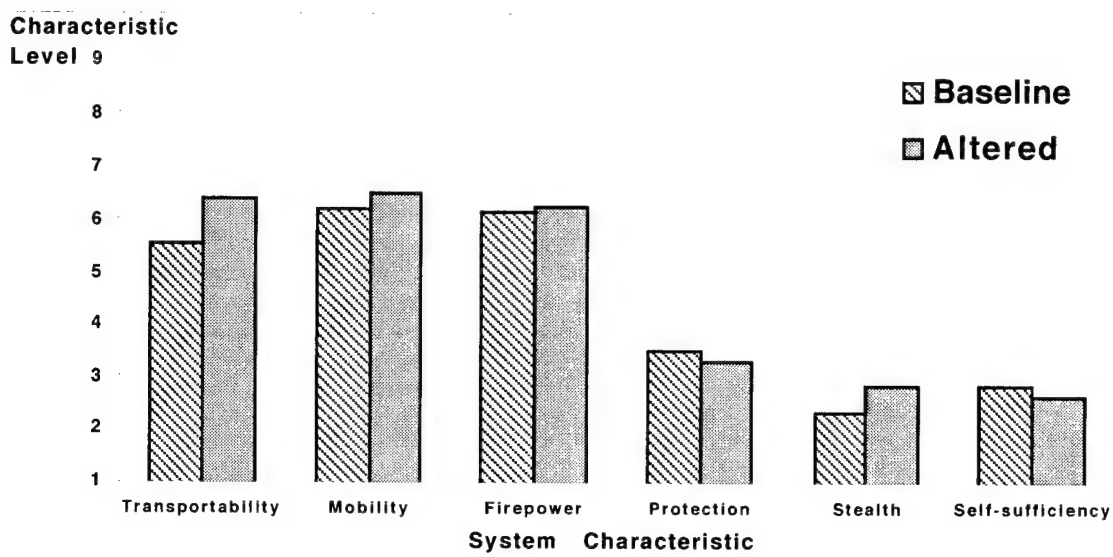



**Figure 10.11. Change in Median System Characteristics of the Heavy Option in the Near Term due to a Doubling of its Contingent of Aircraft and Naval Missile Launchers.**

The principal reason for the sensitivity of these results to the air-to-land-system ratio is the level of importance assigned to transportability in the roles these systems play. The results of the role importance perturbations discussed earlier indicated that if transportability is more important in direct and indirect fire roles, which many of the land systems in these forces play, or less important in air roles, then the force-level transportability would be pulled down closer to the fairly low values of these land systems. Such changes in the role importance ratings would reduce the benefits of adding more air systems, since they would have less influence on transportability—the largest contributor to deployability.

The next two near-term alterations shown in Table 10.21 involve significant changes in the mix of operational concepts used by the heavy and medium options. The first alteration eliminates the use of two concepts, standoff (w/ ground info) and peace keeping/enforcement, by the heavy force, shifting most of their weight to maneuver warfare, and the rest to ambush/envelopment, so that the new usage ratio between these two concepts is 4-to-1. This altered mix is better suited to heavy than its original allocation, and favors it greatly because it focuses on the operational concepts that are rated the highest in the near term. This is reflected in the impact this alteration had on the preference frequencies in the three scenarios. After this change medium was preferred to heavy far less often in all three scenarios, dropping to a mere 8 percent in scenario A, and even lower in the other two scenarios.

The last near-term alteration changes the allocation of operational concepts for the medium option, assigning an importance weight of one half to ambush/ envelopment, equal weights of one fifth each to standoff (w/ ground info) and maneuver warfare, and the remaining one tenth to peace keeping/enforcement. This alteration greatly improved the standing of medium relative to heavy, since it shifts weight to the highest-rated concepts, increasing the preference frequency for medium over heavy to almost 100 percent in scenario A, over 90 percent in scenario B, and nearly 80 percent even in scenario C.

*Far Term*

The first alteration in Table 10.22 increases the number of advanced tactical aircraft in the lean heavy force to 100, and doubles its contingent of Comanche helicopters and advanced naval missile launchers as well. Again, because of the importance assigned to transportability in air roles, adding more self-deployable air systems to this heavy land-based force will tend to increase its effectiveness. This alteration reduced the preference frequency for advanced air + SOF over lean heavy in all three scenarios, pushing it down from 12 to 7 percent in scenario A, and from 6 to 1 percent in scenario B.

**Table 10.22**

**Scenario Preference Frequencies for Medium Versus Heavy in the Far Term, Under Selected Alterations in Option Composition**

| *Option Altered* **Alteration in Composition** | **Preference Frequencies in Future Scenarios** (A) Small-Scale Interventions | (B) Balanced Mix of Contingencies | (C) Major Regional Conflicts |
|---|---|---|---|
| *Lean Heavy* Increase tactical aircraft to 100, double Comanche helicopters and naval missile launchers | 0.12 → 0.07 | 0.06 → 0.01 | 0.00 → 0.00 |
| *Advanced Air + SOF* Increase tactical aircraft to 100, double Comanche helicopters and naval missile launchers, and reduce Apache Longbow helicopters by half | 0.12 → 0.30 | 0.06 → 0.14 | 0.00 → 0.05 |
| *Lean Heavy* Eliminate use of standoff and peace keeping/enforcement concepts, focus on ambush/envelopment and maneuver warfare in ratio of 3-to-1 | 0.12 → 0.00 | 0.06 → 0.00 | 0.00 → 0.00 |
| *Advanced Air + SOF* Use ambush/envelopment half time, standoff (w/ ground info), maneuver warfare rest of time, in 4-to-1 ratio | 0.12 → 0.67 | 0.06 → 0.34 | 0.00 → 0.07 |

The next alteration applied exactly the same set of changes in system numbers to the Advanced air + SOF option, which had the same initial numbers of the three systems affected. This alteration also involves an additional change: the number of improved Apache Longbow attack helicopters was cut in half from 18 to 9. This alteration had a fairly modest impact on the preference frequency results, primarily because these systems already comprised a large fraction of this force. This alteration favored advanced air + SOF, but not enough for it to be preferred to lean heavy more than half the time in any of the three scenarios; its preference frequency reached as high as 30 percent in scenario A, but only increased to 14 percent in scenario B, and 5 percent in scenario C.

The last two alterations in Table 10.22 change the mix of operational concepts used by lean heavy and advanced air + SOF. Like its near-term counterpart, this lean heavy alteration eliminates the use of standoff (w/ ground info) and peace keeping/enforcement by this option. In this alteration, unlike in

the near term, the weight is reallocated mostly to ambush/envelopment, giving it three times as much weight as maneuver warfare. Since these two concepts are also generally rated higher than the others in the far term, shifting weight to them improves the effectiveness of this option. This alteration enabled lean heavy to pull ahead of advanced air + SOF, with preference frequencies of zero, in all three scenarios.

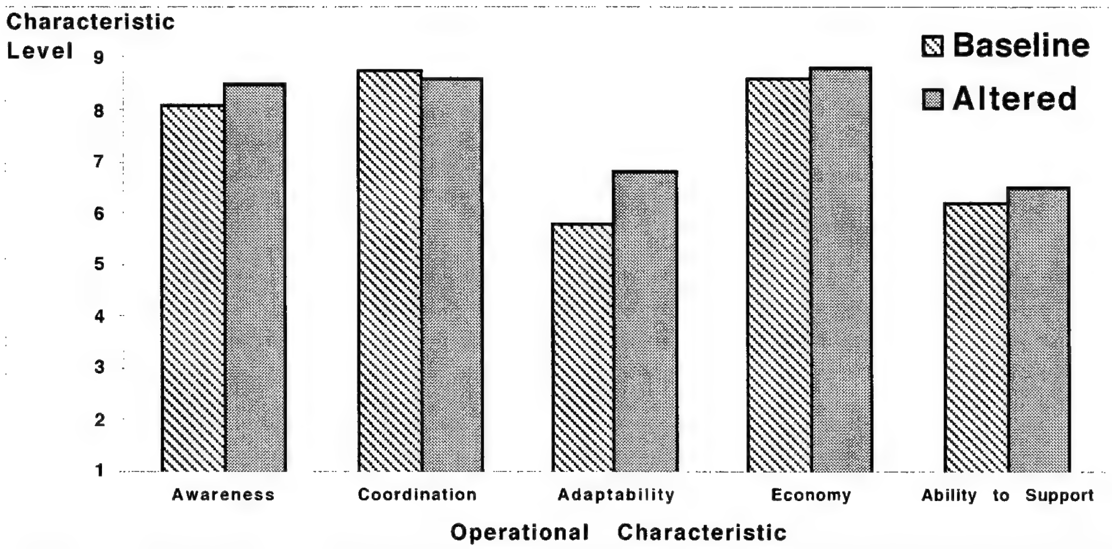



**Figure 10.12. Change in Median Operational Characteristics of the Advanced Air + SOF Option in the Far Term due to a Large Shift in Importance from Standoff (w/ ground info) to Ambush/Envelopment, and some limited use of Maneuver Warfare.**

The final alteration shown in Table 10.22 changes the mix of operational concepts used by the advanced air + SOF option, assigning an importance weight of one half to ambush/envelopment, and split the remaining weight between standoff (w/ ground info) and maneuver warfare in a ration of 4-to-1. This alteration improves this option's effectiveness because it places more weight on the most highly rated operational concept in the far term, ambush/envelopment. Figure 10.12 shows the impact that this alteration had on the force-level values of the operational characteristics of this option; all of them are increased or fall only slightly, and the worst one in the baseline evaluation, adaptability, improves the most, so that the new set of values is more robust across all five characteristics.

This alteration has a substantial impact on the preference frequency in favor of this option over lean heavy in all three scenarios, raising it to about two thirds in scenario A, one third in scenario B, and 7 percent in scenario C. Figure 10.13 illustrates the effect that this option had on the preference surface for advanced air + SOF versus lean heavy, with the plots for the baseline surface inset on the left. The basic shape of the new surface is similar to that of the baseline: a slight depression in the upper left corner, where high-intensity missions matter most, and a steady rise to the right, where low-intensity missions are more important, Under this alteration, however, the elevation on the right is higher, surpassing the 50 percent mark when low-intensity missions are only a few times more important than other types of missions, and the depression in the upper left corner is more pronounced when the offensive evict mission is most important.

## 10.3 CONCLUDING REMARKS

This chapter described results of the fifth phase in the HIMAX process—exploration. It examined selected cases of two types of exploration: model input perturbations, and force option alterations. These carefully and systematically chosen examples provided a variety of insights into the sensitivities of the analysis. This was especially true with regard to the perturbations associated with minority opinions, which diverged significantly from the consensus. The sixth phase of the HIMAX process—interaction—was not implemented in this analysis, so there is no chapter devoted to it. Chapter 11, however, serves a similar function. It re-examines the results presented thus far from a prescriptive viewpoint, then draws out some interesting insights from the results of both this re-analysis and the original analysis—including these exploration findings—and discusses provocative observations regarding the policy choices facing the Army that rely on these insights.

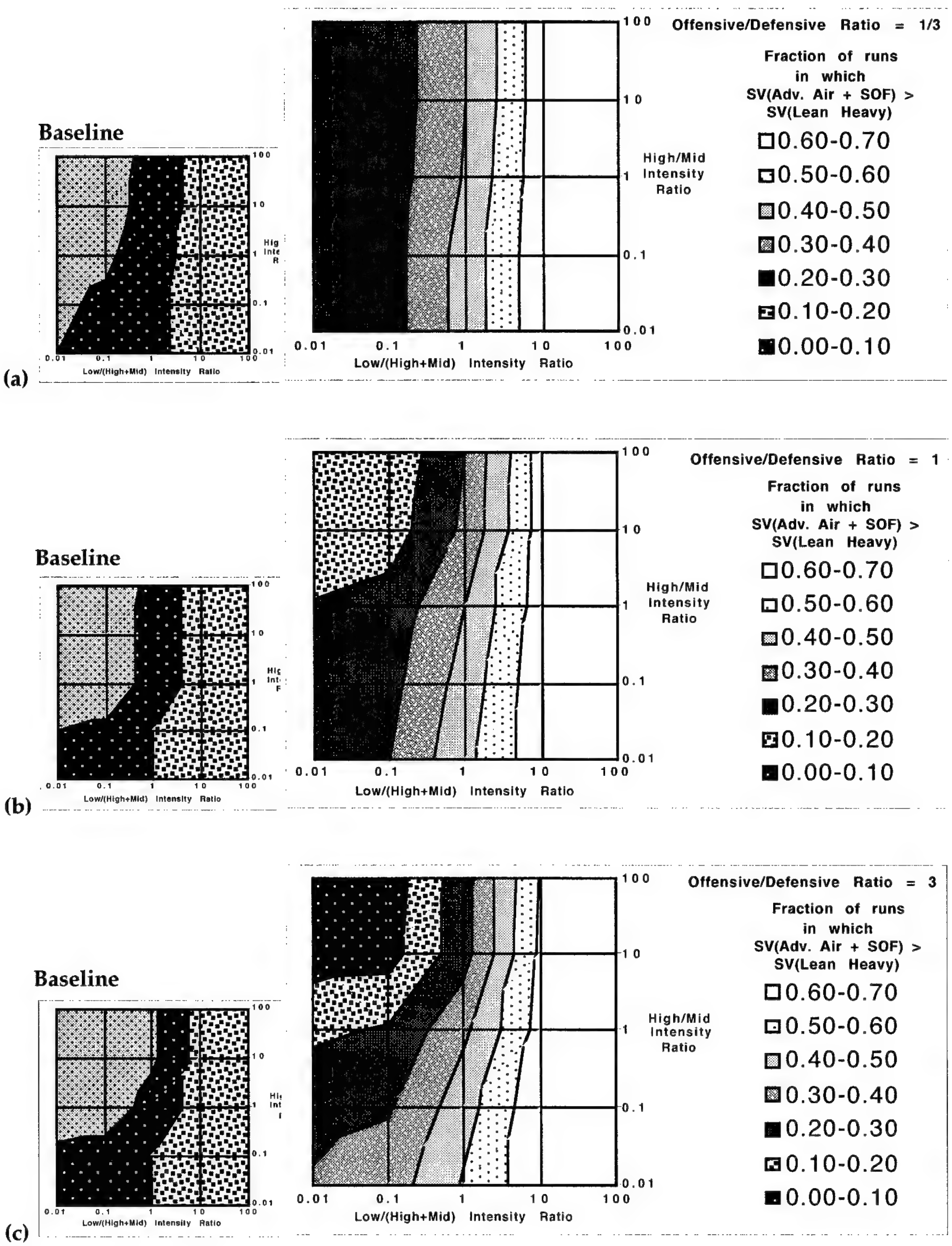



**Figure 10.13. Preference Surface for Advanced Air + SOF over Lean Heavy in Far Term if it uses Ambush/Envelopment one half, Standoff (w/ ground info) two fifths, and Maneuver Warfare one tenth of the time, when: (a) defensive missions are more important; (b) offensive and defensive are missions equally important; and (c) offensive missions are more important.**

# 11. POLICY DISCUSSION

This chapter puts a capstone on the analysis presented in this dissertation. It begins with an overview that discusses how the HIMAX process can be viewed from both descriptive and prescriptive perspectives[76], and relates these parallel viewpoints to a series of key policy questions. The results presented in the preceding chapters provide a descriptive look at military force evaluation. This chapter, however, re-interprets these results from a prescriptive perspective. Several interesting insights are drawn from both of these analyses, and discussed briefly. These insights then form the basis for a series of illustrative policy observations regarding the Army's ongoing transformation.

## 11.1 OVERVIEW

The analysis presented thus far has been descriptive in nature; the experts provided subjective assessments—of general properties, not specific options—that determined the parameters of a model, which evaluated the effectiveness of force options across a range of missions. While the results of this analysis imply that certain options are better under different circumstances, it does not prescribe a particular choice as the best one—unless it happens to dominate all of the others across every mission, and hence every possible security environment.

This chapter looks at the HIMAX evaluation process from a different perspective; it uses the expert-based inputs and model-derived outcomes of the descriptive analysis to conduct a prescriptive analysis of the policy choices facing

---

[76] Stokey and Zekhauser (1978; pp. 13–14) discuss the distinctions between descriptive and prescriptive analysis. They explain that descriptive models "describe the way the world operates" and "illuminate choices by showing us more clearly what [our] choices entail, what outcomes will result from what actions." Prescriptive models, on the other hand, "go further and provide rules for making the optimal choice." Bell, Raiffa and Tversky (1988) consider models that are used for both descriptive and normative purposes as prescriptive.

the Army as it begins to transform itself for the 21st Century. This prescriptive analysis provides useful insights by selecting a plausible, challenging future, and then examining its implications at every level, from which missions will be most prevalent, to what types and combinations of systems and operational concepts would be most attractive in that future.

This decision-oriented prescriptive approach complements the option-oriented descriptive analysis because it looks at the problem in a different way. The descriptive analysis asks the overarching question, what options are available and how good are they in different situations? The prescriptive analysis, however, aims to determine what type of force would be best for a given type of future. Figure 11.1 depicts these two approaches side by side, in terms of the sequence of specific questions they each address. The descriptive analysis starts out with various force components, puts them together to form specific force options, and then determines the characteristics, attributes and mission effectiveness of these options, as well as their overall strategic value in a range of different futures. The prescriptive analysis proceeds in exactly the opposite direction, asking first what the future will be like, then determining which missions will be preeminent in that future, which attributes matter most in those missions, which characteristics contribute the most to those attributes, and then, finally, which options and individual components provide the best mix of these key attributes and components for the envisioned future.

Figure 11.1 also includes two other very important features that connect these parallel analytical perspectives to each other through real policy choices: "Area Studies and Intelligence Analysis" at the bottom; and "R&D, Acquisition, Doctrine and Training" at the top. Area Studies and Intelligence Analysis connect the end of the descriptive analysis to the beginning of the prescriptive analysis. This recognizes that a large body of research, integrated with first-hand knowledge and experience, must be drawn upon to understand the world, both as it exists today and as it is likely to evolve in the future, in order to project, with

any degree of confidence, what the global security environment will be like in a given time frame. While the illustrative prescriptive analysis presented here simply picks a scenario for certain type of future, and examines its implications, this choice should ideally be motivated by research and intelligence indicating that this sort of future is likely. Additional scenarios that represent other quite different, but equally plausible scenarios should also be examined.

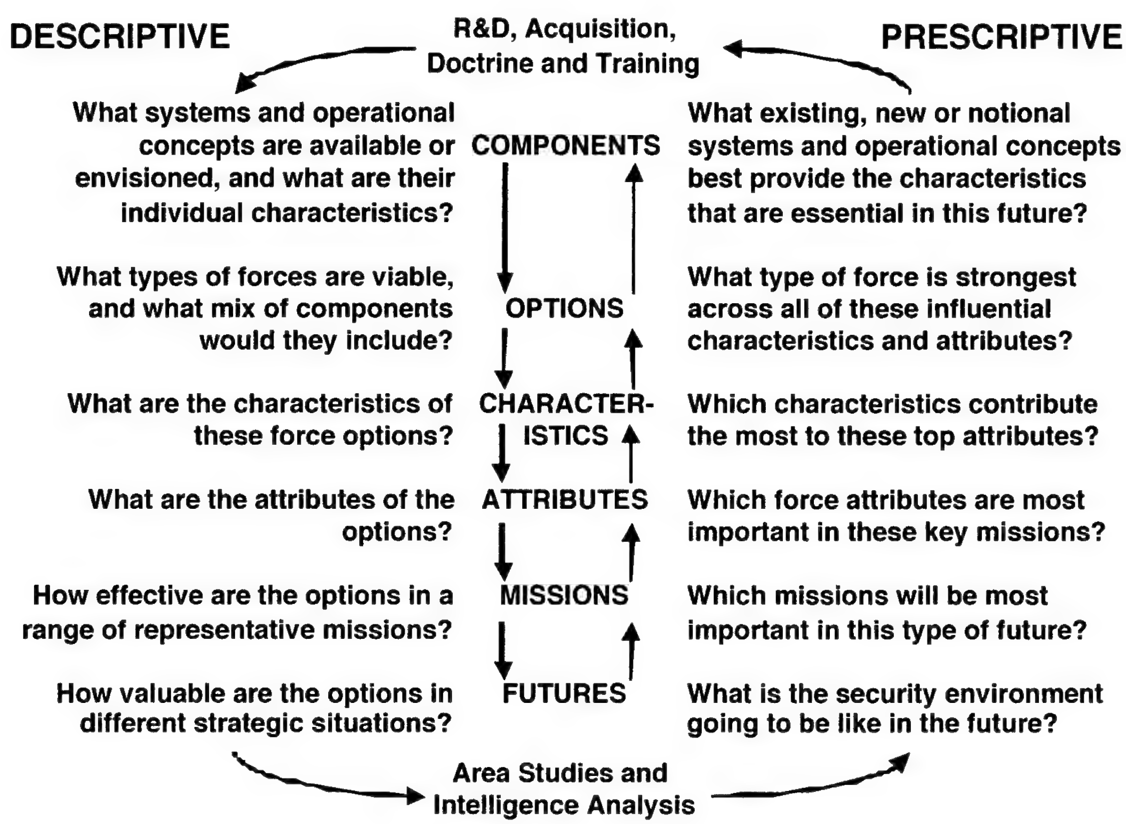



**Figure 11.1. Side-by-Side Comparison of the Descriptive and Prescriptive Perspectives on the Analysis of Future Force Options**

R&D, Acquisition, Doctrine and Training, the second added feature in Figure 11.1, is equally important, since it connects the end of the prescriptive analysis back into the beginning of the descriptive analysis. This indicates that any insights gained from the prescriptive analysis should be funneled back into the design and development of new systems and operational concepts, which can then be incorporated into new force options to be considered in subsequent

iterations of descriptive analysis. If the experts providing inputs for the evaluation are also the principal decision makers, then the whole prescriptive analysis, including feedback through changes in R&D, acquisition, doctrine and training to create new systems and operational concepts, would really be part of the interaction phase of the HIMAX process. Otherwise, the prescriptive analysis would follow a full implementation of the HIMAX process, including interaction with the participating experts, and the feedback to policy choices regarding R&D, acquisition, doctrine and training would take place implicitly through dissemination of the results and findings of this process.

## 11.2 ILLUSTRATIVE PRESCRIPTIVE ANALYSIS

The purpose of this prescriptive analysis is to demonstrate how the results of the HIMAX process, and the expert inputs used to derive its parameters, can be interpreted from a normative perspective to produce useful policy insights. This illustrative example begins by picking a specific type of future—similar to one of the three scenarios described in Chapter 9—that provides a backdrop for the analysis. The missions that are most prevalent in this type of future are then identified, and the relative importance of the various attributes in these missions is discussed. Next, the characteristic contributions for these key attributes are examined to determine which characteristics are most influential for each of them. The HIMAX results are then examined to see how the various options considered in each time frame fared on these key attributes and characteristics, and how the contributions of their individual components fit into this picture. The implications of these results for the development of new systems and operational concepts are drawn out in this discussion, and any of the changes highlighted during the exploration phase that are pertinent to these conclusions are discussed as well.

### Most Prevalent Missions the Envisioned Type of Future

In light of the challenges that the U.S. Army faces today from a growing array of prolonged peacekeeping commitments, particularly in Bosnia and Kosovo, it is reasonable to consider a future in which small-scale interventions like these, and the wars that precipitate them, dominate the international security environment. In such a future, U.S. forces would frequently be called upon to perform low-intensity missions, while other types of missions would be quite rare. It is also reasonable, though perhaps not as likely, that U.S. policy will, in response, shift more towards pre-empting these conflicts by mounting a fast, effective defense, instead of waiting for events to unfold and then having to engage in high-intensity offensive operations. Thus, protect-type missions, such as defending minority groups from oppressive regimes, would be most prevalent in this future, followed by the stabilization missions to secure the peace. U.S. forces would generally hand off these peacekeeping duties to regional forces as soon as some degree of stability has been achieved, which should occur sooner since the conflict was pre-empted. Thus, in this type of future, protect missions would be the primary focus, and stabilize missions would be secondary, with all other missions far less important. This type of future is very similar to the "Small Scale Interventions" scenario described in Chapter 9, which places over 68 percent of its weight on protect, and almost 23 percent on stabilize, but just 3.4 percent each on halt and defend, and only 1.1 percent each on evict and raid. While this is a fairly extreme case, the insights it provides are also applicable to other futures where the mix of missions is more balanced, but still emphasizes low-intensity missions.

### Most Important Attributes

The key attributes to consider in this type of future, where protect and stabilize missions are so prevalent, are the ones that these missions rely on most heavily. Figure 11.2 shows the distribution of importance among the six attributes for these two low-intensity missions. The implications of these

weights, and the expert assessments they were derived from, are discussed separately below for protect first, and then for stabilize.

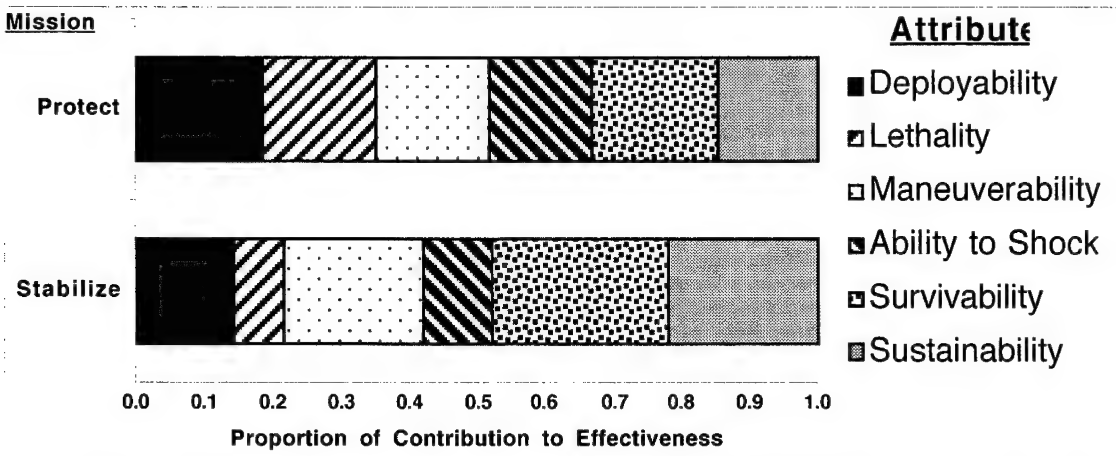



**Figure 11.2. Distribution of Attribute Contributions to Effectiveness in the Low-Intensity Missions that Are Most Prevalent in a Future Dominated by Small Scale Interventions**

*Protect.* The distribution of attribute contributions to effectiveness in the protect mission is quite balanced; every attribute makes a substantial contribution, and these contributions are all fairly similar in size. This balance implies that, based on the consensus opinion of the experts, this mission is challenging because of its breadth, so it requires a robust force that is not weak on any attribute. Two of the attributes do, however, contribute slightly more than the others in this mission: deployability and survivability. Both have importance weights of almost 0.19, so together they account for a bit less than two fifths of all the contributions. It is also important to consider the consistency of the expert assessments that the weights for these key attributes were derived from, especially in this mission, where the attribute contributions are so similar. The experts disagreed most on the ratings for ability to shock and sustainability, the two attributes that received the lowest weights overall. If these ratings were lower, then deployability and survivability would pull further ahead of the other attributes, but if they were higher, then the attribute weights would be pushed closer to parity, or even beyond, in favor of ability to shock and sustainability.

There is no clear trend, however, in the expert responses that would support an across-the-board shift of these ratings in either direction. But, the responses do support shifts that would favor deployability; most or all of the experts whose responses diverged most significantly from the median ratings for this attribute thought it was more important than the others. The attribute perturbations chosen in the exploration phase involved just such shifts, and had a substantial impact in both time frames. Which attributes are most important for the protect mission, and hence for a future dominated by small scale interventions? Because of the minority opinions, deployability should be at the top of this list, followed by survivability, even though the two have the same baseline weights.

*Stabilize*. The distribution of attribute contributions to effectiveness in the stabilize mission is less balanced than it is in the protect mission; as Figure 11.2 shows quite clearly, there are a few attributes that are more important than the others in this mission. Survivability is the most important attribute, with over a quarter of all the contributions. Sustainability and maneuverability are also major contributors, each not far behind with over 20 percent. Together these three attributes account for more than two thirds of the contributions to effectiveness in the stabilize mission. The discrepancies in the expert responses for this mission's attribute importance ratings are quite similar to those of protect, the other low-intensity mission. There is again some support for an upward shift in the importance of deployability, especially relative to ability to shock and sustainability. The large, controversial perturbation selected for this mission examined the impact of just such a shift—albeit the most extreme one justifiable—and found that it had a substantial impact on option rankings, particularly in the far term. There was also some support for a modest rise in the importance of deployability relative to survivability, the top-rated attribute in this mission. Moreover, there was very consistent support for an increase in the rating of survivability relative to sustainability, the number two attribute, from equally to moderately more important (1 → 3). If plausible rating changes along these lines were combined they would push the weight placed on deployability

up to about 0.20, enough for it to displace sustainability and join maneuverability in a tie for the second most important mission, with survivability even more entrenched as the top attribute in the stabilize mission, with a weight near 0.30. Since survivability is also tied with deployability as the top attribute in the protect mission, these two attributes are both of central importance in a future where small scale interventions are predominant.

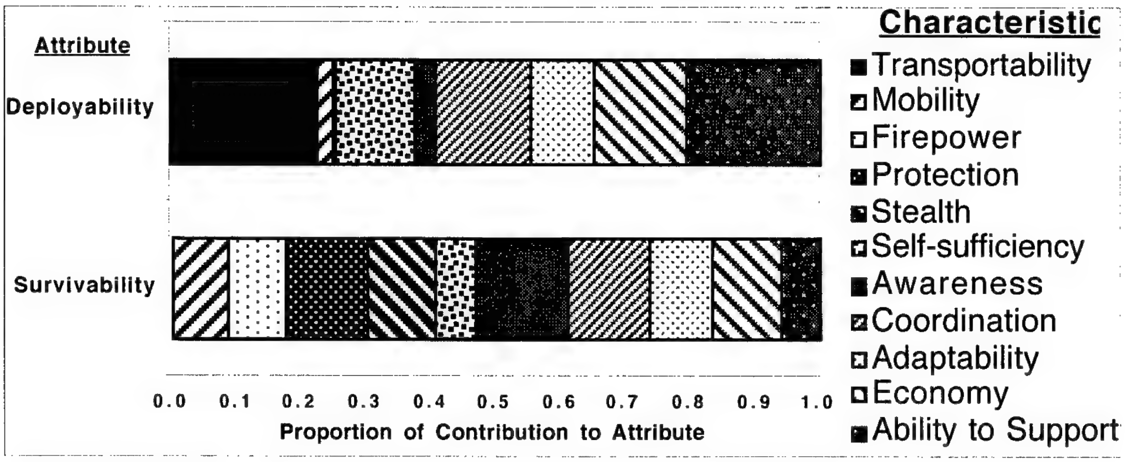



**Figure 11.3. Distribution of Characteristic Contributions to Deployability and Survivability, the Attributes that Are Most Important in a Future Dominated by Small Scale Interventions**

### Most Influential Characteristics

The distribution of contributions from the various force characteristics to the two top attributes are markedly different, as Figure 11.3 shows very clearly. Deployability receives its largest contribution from transportability (nearly 0.23), while survivability hardly relies on this characteristic at all. Similarly, none of the weight for deployablity is placed on protection and stealth, the two most important system characteristics for survivability, and very little emphasis is put on awareness, which is survivability's top operational characteristic. Also, while deployability places a lot of weight on ability to support (over 0.20), and a moderate amount on self-sufficiency (over 0.12), survivability receives only modest contributions from these two logistically-oriented characteristics (less than 0.06 from each). Both of these two key attributes do, however, place a fairly

high emphasis on coordination and economy (0.14 each for deployability, and over 0.10 each for survivability).

All of these characteristics were significant contributors to the two key attributes when the baseline inputs were used, but it is worthwhile to examine the degree to which the experts agreed on the assessments these inputs were derived from. They were actually in close agreement on the direct (i.e., main effect) contribution ratings of the top characteristics for both attributes: transportability and ability to support for deployability (with one or two exceptions); and awareness, protection and stealth for survivability. But, the response ranges for the ratings of synergistic interactions involving these characteristics were rather high. This should not be of concern, however, since the large ranges were in most cases attributable to one or two experts, whose ratings were much lower than those of the others. Also, half of the experts believed that self-sufficiency makes at least a very strong (7 or higher), rather than a bit-more-than-moderately strong (4) direct contribution to deployability, so its total contribution could actually be a bit higher than its baseline value, possibly bringing it even with ability to support for the number two spot. There was also quite good agreement among the experts on both the direct and synergistic contributions of coordination and economy to deployability and survivability; there was always a couple of dissenting experts who gave these contributions low ratings, but most of the experts' responses were very similar. In the case of transportability, the same dissenter gave the lowest rating (0) to all of the direct contributions from the operational characteristics. If this person is right about some of these ratings, as one of the perturbations highlighted in Chapter 10 assumes, transportability's contribution to deployability would be much larger, favoring lighter, air-mobile forces over heavier, land-based options.

Thus, there are five characteristics that are the most influential contributors to each of the key attributes for the envisioned future: transportability, self-sufficiency, and ability to support for deployability; and awareness, protection,

and stealth for survivability; and coordination and economy for both. The value functions assigned to these characteristics are important because they affect the attribute calculations. Transportability, awareness and coordination use an s-shaped function, so their values are a bit low at lower scale levels and a bit high at higher levels, and any shifts would have the most impact at the middle levels. These assignments tend to amplify the importance of these characteristics, especially transportability and awareness, which are already the most important contributors to deployability and survivability, respectively. Because the key components of ground-based forces are usually rated at the middle scale levels (3–7) on these characteristics, their s-shaped value functions will tend to accentuate differences among the options. Protection, self-sufficiency and ability to support all use a linear value function, so their values exactly equal their rating levels, and differences in these characteristics among the options are captured equally at every level. Stealth, however, uses a convex function, so its values are always lower than the corresponding scale levels, and increases in value are very small at low scale levels, but get increasingly larger higher up the scale. Thus, stealth is important for differentiating options that have fairly high, but somewhat different levels of this characteristic, like options that use a lot of air and SOF systems. Economy, on the other hand, uses the concave function, so its values are always higher than the corresponding level, but rise by ever smaller amounts at higher levels; options that are not very economic can be differentiated more easily based on this characteristic.

## Most Promising Options and Components

It is quite a challenge to envision an ideal force option for a future in which low-intensity missions, like stabilize and especially protect, are highly prevalent. The distribution of importance among all the attributes is so balanced in the protect mission that no attribute should be neglected entirely. Nonetheless, it is still helpful to focus on the two attributes that matter the most in this future: deployability and survivability. These attributes rely on quite different mixes of

characteristics, so it is difficult to construct a viable force option that achieves reasonably high levels of both. For a force to be highly deployable it should be as transportable and self-sufficient as possible, and use operational concepts that make it relatively easy to support. On the other hand, to be survivable a force should be well-protected and stealthy, and use operation concepts that heighten its awareness. And, of course, operational concepts that enable it to be well-coordinated and economic will contribute to both attributes. Some of these goals are at odds with others; for example, well-protected systems are usually less stealthy, transportable and self-sufficient that those with less protection.

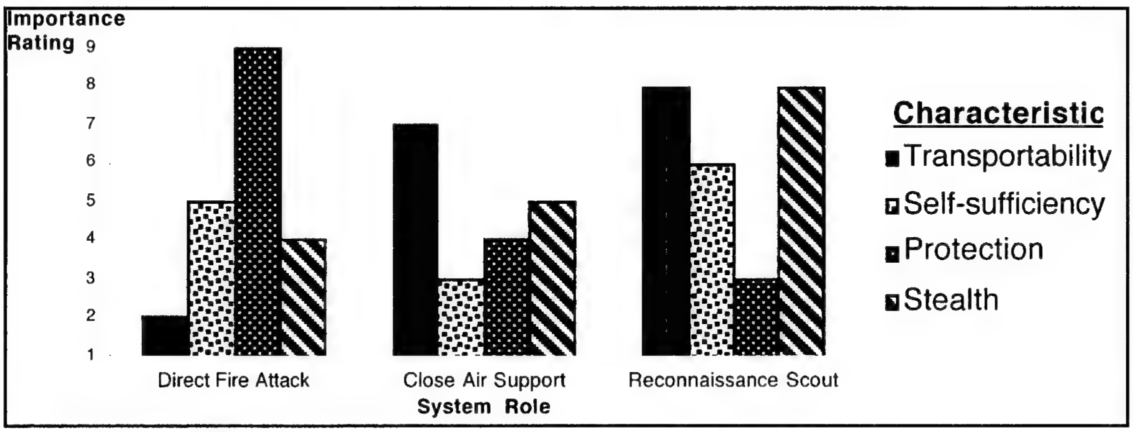



**Figure 11.4. Representative Selection of System Role Ratings for System Characteristics that Are Most Influential in a Future Dominated by Small Scale Interventions**

In selecting systems for a force option to handle this type of future, the role each type of system is intended to play must be considered in addition to its individual characteristics. Playing certain roles in a force can enable a system to compensate for other systems' weaknesses with their strengths. Figure 11.4 shows the system role importance ratings for three representative system roles: direct fire attack, close air support, and reconnaissance scout. These ratings indicate that transportability is much more important for reconnaissance systems and aircraft than it is for direct-fire systems. Self-sufficiency, however, is moderately important for reconnaissance and direct-fire systems, but less important for air systems. Thus, highly transportable air systems and less

transportable, but relatively self-sufficient direct-fire systems can complement each other; the air systems pull up transportability, while the direct-fire systems pull up self-sufficiency, together making the force more deployable. Similarly, protection is extremely important for direct-fire systems, but only moderately important for reconnaissance systems, while the opposite is true for stealth. Thus, in a force that includes a mix of direct-fire and reconnaissance systems, the well-protected, but not so stealthy direct-fire systems can pull up the overall protection level, while the elusive, but vulnerable reconnaissance systems make it more stealthy as a whole.

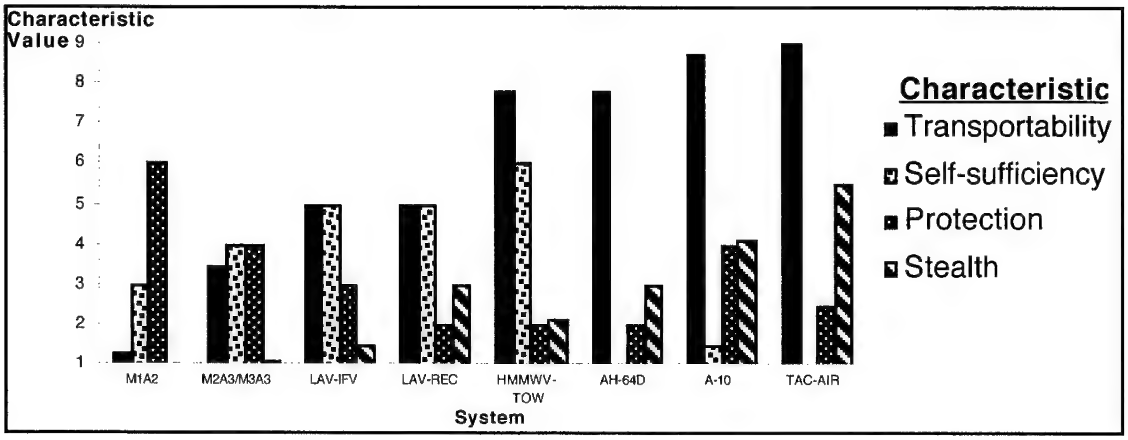



**Figure 11.5. Median Values of System Characteristics that Are Most Influential in a Future Dominated by Small Scale Interventions, for a Representative Subset of Near-Term Systems**

A quick survey of the systems considered in the positive analysis serves to illuminate these issues and highlight the key force composition tradeoffs. Figure 11.5 shows the median values of the most influential system characteristics for a selected subset of the near-term systems. These values illustrate how difficult it is to optimize the mix of systems in a force. Transportability and self-sufficiency track together for the ground vehicles; a heavy armored vehicle like the M1A2 has low levels of both, while a lighter vehicle like the LAV-IFV has moderate levels of both, and a very lightweight vehicle like the HMMWV-TOW has higher

values.[77] Aircraft, like the AH-64D, A-10 and TAC-AIR, however, are highly transportable because they can self-deploy, but they also have extremely low self-sufficiency values because they require so much fuel, maintenance and other support to operate effectively. Thus, the deployability of a ground force can be increased by adding aircraft, or by using lighter, more self-sufficient vehicles.

Lighter vehicles, however, generally have less protection than heavier ones, so a force that relies on them will tend to be less survivable. In the near term, none of the available ground vehicles adequately address this problem. As Figure 11.5 shows, the M1A2, which rates very low on transportability and is not that self-sufficient, has a fairly high level of protection, but it is not very stealthy, primarily because of its size and its conspicuous behavior on the battlefield. The M2A3/M3A3 has less protection, but fares a bit better on the other three key characteristics because it is lighter, more efficient and draws less attention to itself. Both LAV variants, which have moderate levels of transportability and self-sufficiency, are quite poorly protected and not very stealthy. The LAV-IFV does better on protection, while the LAV-REC is more stealthy, so these two variants tend to complement one another. Also, as Figure 11.4 shows, air systems are stealthier than ground vehicles, so adding aircraft to a ground force will raise its overall stealth somewhat, which may make it a bit more survivable. While the near-term air systems, except for the A-10, are not very well-protected, this should not lower the survivability of a mixed force very much, if at all, since protection is not very important in air roles.

Some of the systems available in the far term have characteristics that can address this problem by making a balanced contribution to both deployability and survivability. In particular, as Figure 11.6 shows, variants of the notional FCS are as transportable and even more self-sufficient than the near-term LAV

---

[77] Figure 11.5 shows the values—not the ratings—of key characteristics for a number of representative systems. So, for example, differences in transportability among the systems have been accentuated by the s-shaped value function assigned to this characteristic.

vehicles, and combine moderate to high values for both stealth and protection, as compared to the low to moderate values of the LAV variants. They accomplish this by incorporating and integrating advanced technology in lightweight armor, active protection systems, signature management, and fuel-efficiency. Of course, all of this new technology may be quite expensive, and require considerable time and effort to develop, so the cost and availability of an FCS-based force would have to be compared to the benefits it would provide, both in terms of overmatch and versatility. Nonetheless, if this type of vehicle is viable, it would bring together the mix of characteristics that a medium-weight force needs in order to be both deployable and survivable enough to be robustly effective in a wide range of challenging futures, including the one examined here. Additional far-term systems, like the AHMV and the RAH-66, could also make a future force still more deployable by providing it with an even earlier, yet reasonably potent ground presence in advance of an FCS-based medium-weight force.

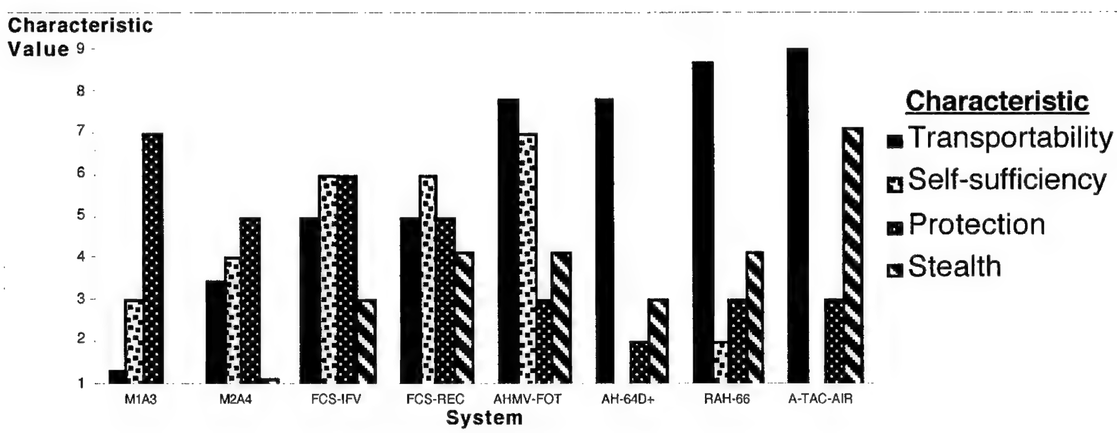



**Figure 11.6. Median Values of System Characteristics that Are Most Influential in a Future Dominated by Small Scale Interventions, for a Representative Subset of Far-Term Systems**

The future under examination here favors operational concepts that are balanced; deployability requires high levels of ability to support, while survivability requires lots of awareness, and both attributes benefit from more coordination and economy. In both time frames, ambush/envelopment and maneuver warfare have the highest and most balanced operational characteristic

ratings. In the near term, as Figure 11.7 shows, these two concepts have the highest or second-highest values of awareness, coordination and economy, and are both within two levels of the highest value for ability to support. Maneuver warfare is stronger on awareness than on ability to support, so it contributes a bit more to survivability than it does to deployability. Ambush/envelopment, however, is has a more balanced mix of these characteristics, so it contributes about equally to both key attributes. Figure 11.8 shows that the two top concepts are even more dominant in the far term: ambush/envelopment has the highest possible values for economy, coordination and awareness, and is within about one level of the highest ability to support value, while maneuver warfare has close to the same levels for awareness, economy and ability to support, but is about one level behind for coordination. In this time frame, both of these concepts contribute a bit more to survivability than they do to deployability.

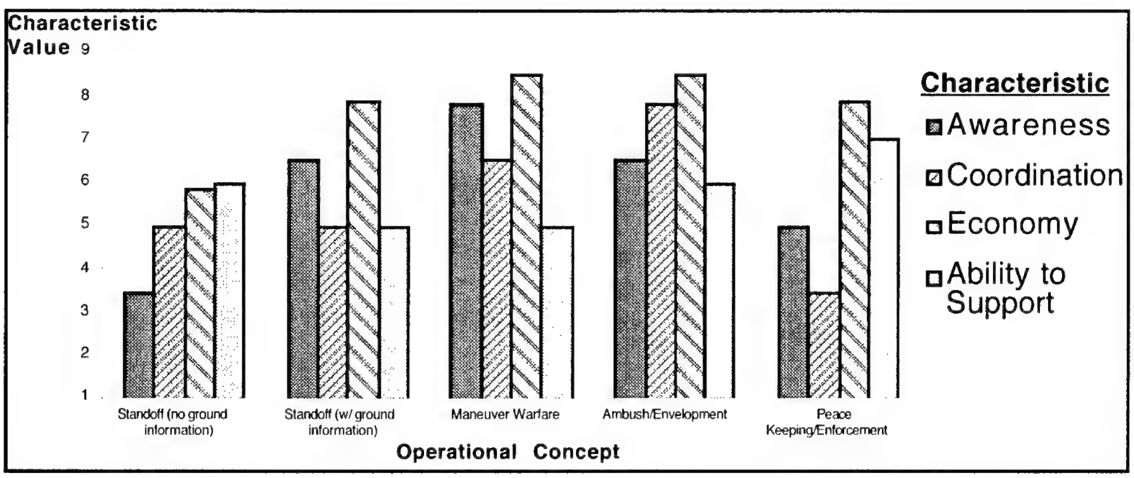



**Figure 11.7. Median Values of Operational Characteristics that Are Most Influential in a Future Dominated by Small Scale Interventions, for Near-Term Operational Concepts**

The other operational concepts also make quite different contributions to the key attributes. In both time frames, standoff (no ground information) contributes more to deployability because of its emphasis on ability to support, while standoff (with ground information) has a bias towards survivability due to its higher awareness values. Peace keeping/enforcement, however, is a much

stronger contributor to deployability than to survivability in the near term, with the highest value for ability to support and a relatively low awareness value, but in the far term, its contributions to the two key attributes are more balanced due a large increase in its awareness value.

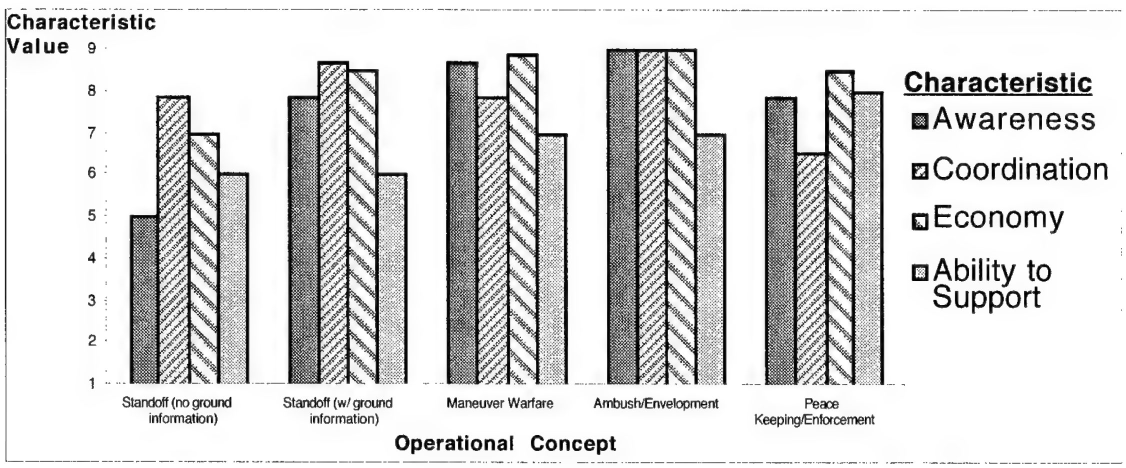



**Figure 11.8. Median Values of Operational Characteristics that Are Most Influential in a Future Dominated by Small Scale Interventions, for Far-Term Operational Concepts**

The extent to which these favored operational concepts can be used in low-intensity missions is not clear, however. The proportions assigned to the various concepts are fixed for each option—they can not vary across missions—and are meant to reflect the constraints that each option faces, in terms of which sorts of operations it must be able to perform. Ideally, all of the options would use the best operational concept all the time, or mix the best couple of concepts, using each in the missions that suit its strengths. Of course, this ideal mix usually does not match with each option's requirements, so the assigned proportions must take into account such implicit tradeoffs, together with the concepts' merits. The force option alterations examined for both time frames during the exploration phase showed that even partial shifts towards the more favored concepts could, if large enough, have a substantial impact on option preferences. This implies that there is an incentive to make such shifts, so in future applications it may be

helpful to constrain these proportions more explicitly for each type of force, and consider allowing them to vary across missions.

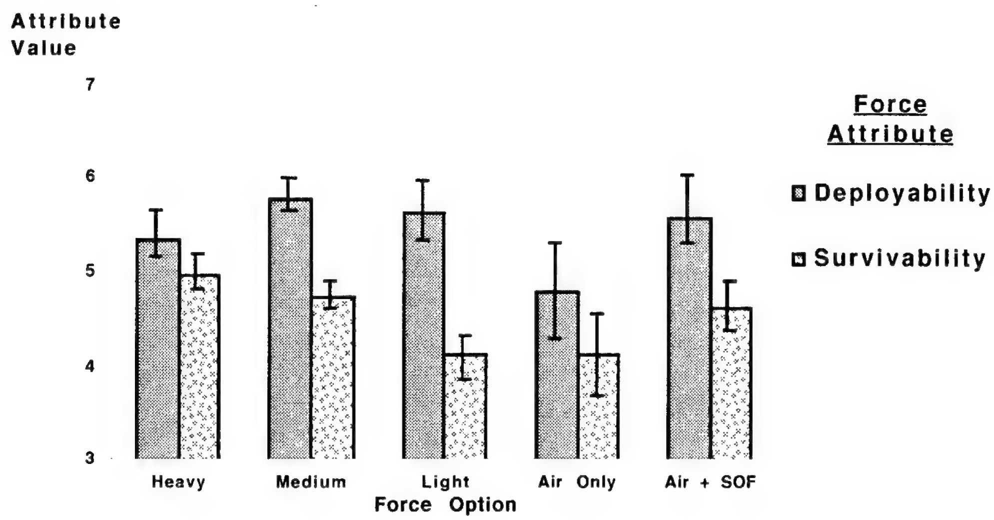



**Figure 11.9. Value Distributions of Attributes that Are Most Important in a Future Dominated by Small Scale Interventions, for Near-Term Options**

When all of the characteristic contributions are combined together there may be unexpected interactions and effects, so it is instructive at this point to examine the attribute values of the options in each time frame. Given the roles that the various near-term systems play, and the relative importance of the key characteristics in these roles, the LAV-based medium option, with its higher levels of both transportability and self-sufficiency, should provide at least as much deployability as the heavy option. Figure 11.9 shows that the LAV-based medium option is, in fact, consistently more deployable than the heavy option, but only by a fairly modest margin of less than half an interval. Two other options, light and air + SOF, are also not that far behind, so they may be a bit more deployable than medium in some situations. The medium option's lead in deployability is actually quite robust, however, since the systems playing air roles may not be so important in determining force-level transportability. This perspective is justifiable if ground vehicles are the lowest common denominator in the deployability of a force, such that it can't start fighting in earnest without

them. In this case, which was examined in one of the perturbations highlighted in Chapter 10, a force would have to rely more on the characteristics of its ground systems for deployability, thus making a medium-weight force even more attractive, especially for low-intensity missions.

The heavy option is the most survivable of the near-term options, but the medium option comes in a fairly close second. This result is not unexpected because of heavy's superior protection, and its substantial use of maneuver warfare, which has the highest value for awareness among all the available operational concepts. The air + SOF option was also fairly survivable as well, in spite of its relatively low level of protection, because it had very high overall levels of both stealth and awareness; its use of elusive SOF teams and aircraft made it stealthy, while its exclusive reliance on the standoff (with ground information) provided it with excellent awareness.

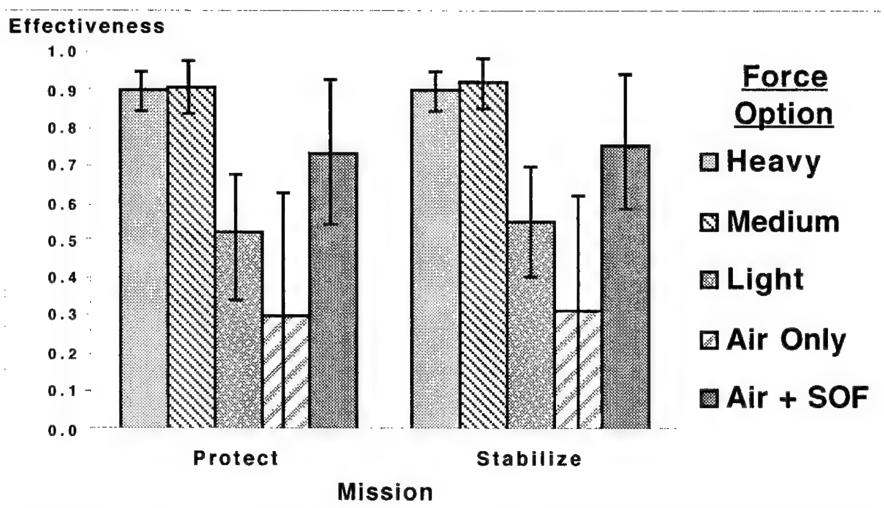



**Figure 11.10. Effectiveness of Near-Term Options in Missions that Are Most Prevalent in a Future Dominated by Small Scale Interventions**

It is not immediately obvious which near-term is the most effective for the two most prevalent missions, protect and stabilize, since medium is the most deployable, while heavy is the most survivable. Figure 11.10 shows that these two options are quite evenly matched in the two key low-intensity missions,

although medium is slightly more effective, on average, with a somewhat larger advantage in stabilize than in protect. These differences may seem quite small, but because the effectiveness distributions are correlated, they are actually fairly significant. When the two options were compared directly, medium was more effective than heavy 58 percent of the time in protect, and 60 percent in stabilize.

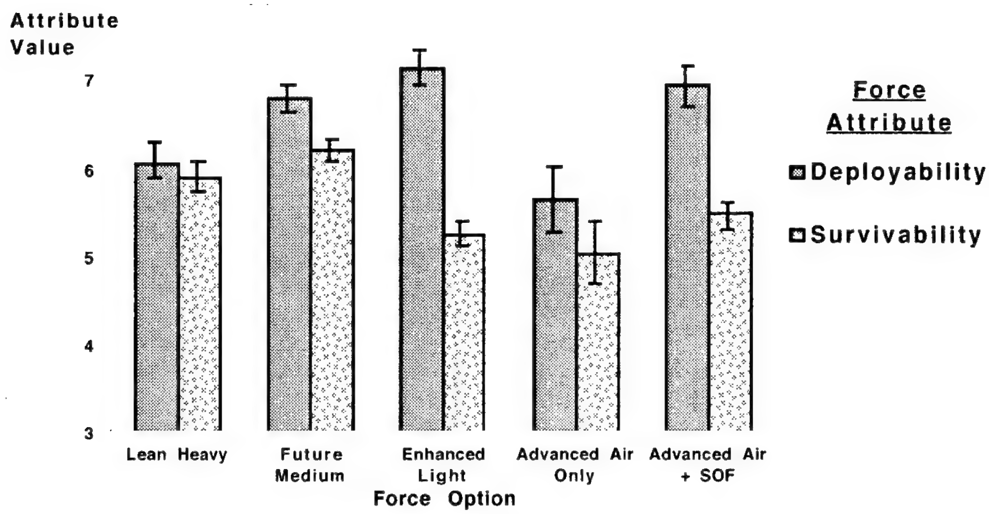



**Figure 11.11. Value Distributions of Attributes that Are Most Important in a Future Dominated by Small Scale Interventions, for Far-Term Options**

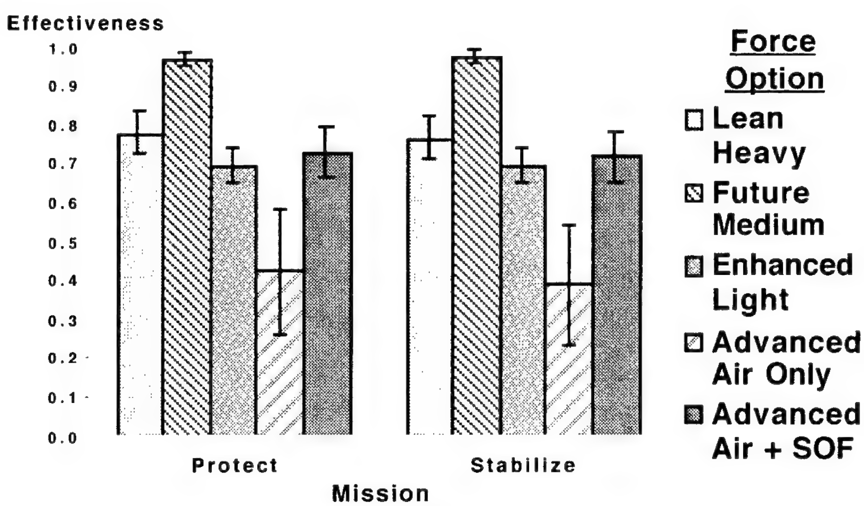



**Figure 11.12. Effectiveness of Far-Term Options in Missions that Are Most Prevalent in a Future Dominated by Small Scale Interventions**

In the far term, the FCS-based future medium option is dominant because of its balanced characteristics. The impact of this balance is evident in Figure 11.11, which shows the value distributions for the deployability and survivability of the far-term options. Future medium has the third highest median value of deployability, with both enhanced light and advanced air + SOF ahead of it by a fairly small margin. It compensates for this deficiency by being much more survivable than these two options, and surpassing even the lean heavy option, primarily because its FSC vehicles combine moderately high levels of both protection and stealth. Indeed, as Figure 11.12 shows, the future medium option was by far the most effective of the far-term options in both of the key missions.

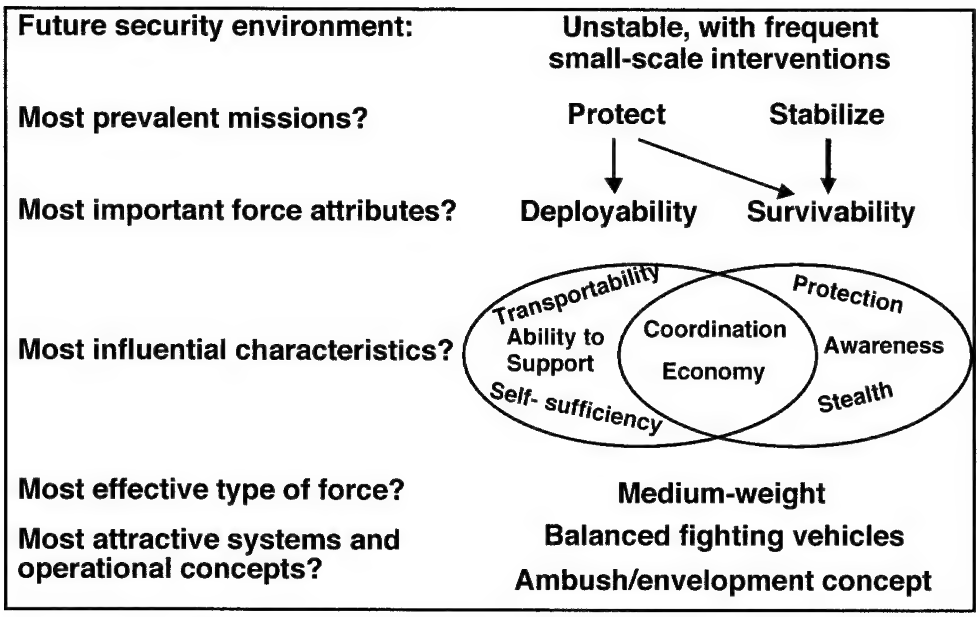



**Figure 11.13. Summary of the Prescriptive Analysis Findings.**

## 11.3 INSIGHTS DRAWN FROM ANALYSIS

### Prescriptive Insights

In a future dominated by frequent complex conflicts, U.S. forces may have to respond quickly and effectively to perform low-intensity missions in diverse and far-flung parts of the world, with little advanced warning. The results of the

prescriptive analysis, which are summarized in Figure 11.13, indicate that there are a number of strategies for constructing force options that are well-suited for this sort of security environment. These force composition strategies, which are discussed below, all aim to improve the deployability or survivability of a force, since these two attributes are the most important in the low-intensity missions that are so prevalent in this future.

*Use a mix of air and land systems.* Air systems, including attack helicopters, tactical aircraft, and naval missile systems, are more transportable than heavy or even medium-weight vehicles, so including a mix of systems from both categories, rather than just ground vehicle alone, will increase the overall transportability of a force, and therefore improve its deployability. This effect is magnified if transportability is much more important for systems playing air roles than it is for those playing direct-fire roles, since this implies that self-deploying air systems contribute more to the overall transportability of a force than less-transportable direct-fire ground vehicles. A more deployable force, consisting of a mix of air and land systems, would be especially attractive in a future where protect-type missions are the most frequent and important.

*Use a mix of direct-fire and reconnaissance systems.* The principal difference between reconnaissance and direct-fire vehicles is their behavior. Direct-fire systems draw attention to themselves when they fire, while reconnaissance systems keep a low profile and try to avoid detection as they gather and share information. This difference alone makes reconnaissance systems more stealthy. These systems tend to have less protection, however, so that they can weigh less and have greater mobility. If the roles these systems play take advantage of their strengths, and downplay their weaknesses, then including both types of systems in a force will tend to make it more survivable and more deployable. Specifically, if reconnaissance roles strongly emphasize transportability and stealth, while direct-fire roles emphasize protection, then a mixed force will have higher overall values for all three characteristics. Thus, a ground force with more

reconnaissance systems will be more survivable and deployable, making it more effective in low-intensity missions, especially those aimed at stabilization.

*Use lighter vehicles with balanced characteristics.* Rather than having to rely on different force components to jointly provide deployability and survivability, it would be better to build a force around systems that each provide sufficient levels of the characteristics that contribute the most to these key attributes. Currently, medium-weight vehicles like the LAV-III[78] are generally more transportable and more self-sufficient than heavy vehicles, but usually also have considerably less protection, since they lack extensive armor, and are not that much more stealthy. Thus, using such systems in place of heavy armored vehicles, like the M1A1 and the M2A3/M3A3, would improve the deployability of a force, but would also reduce its survivability. If these lighter vehicles are also more stealthy and have better protection, then they would be less vulnerable and would improve force-level survivability. Adding relatively light-weight defensive features—like an active protection system, or a suite of passive countermeasures—could increase the protection level of these vehicles without substantially reducing their transportability. Using advanced signature management and camouflage techniques, as well as sophisticated deception tactics, could also improve the stealth of these vehicles without changing their size and weight. Such improvements, whether added on to existing systems in the near term, or designed into future systems, are core elements of a robust medium-weight force. Having balanced characteristics would free such a force from relying too much on uncertain role relationships with air and reconnaissance systems to ensure its survivability and deployability. Such a force could also be scaled and re-configured for different missions more easily, since it components are more versatile.

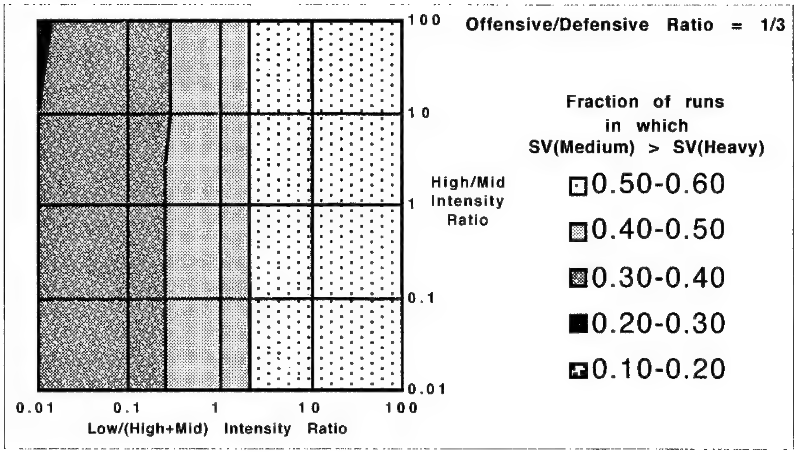
---

[78] The Army is considering many types of vehicles, including the LAV-III, for its new medium-weight brigade combat teams. Steele (2000) describes the vehicles that participated in the platform performance demonstration held at Fort Knox, Kentucky early in 2000.

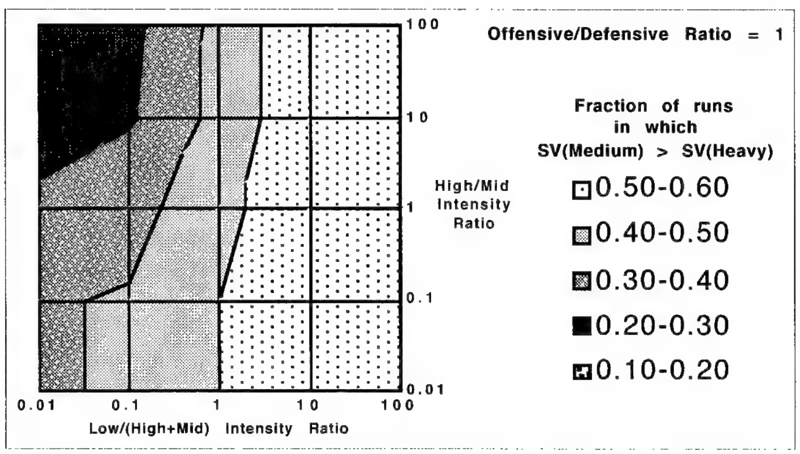
*Use ambush/envelopment operational concept more often.* In both time frames, ambush/envelopment is the most balanced of the operational concepts available. While it does not always have the highest value for the major contributors to both survivability and deployability, its values are consistently high relative to the other concepts, especially in the far term. If these characterizations are accurate, using this sort of operational concept more often will make an option more effective, especially in low intensity missions. Thus, all of the options should ideally shift towards using this concept more frequently. Of course, there are practical limitations on how much each type of force can use this concept, but these limits should be pushed as far as possible to take advantage of the benefits that ambush/envelopment has to offer.

## Descriptive Insights

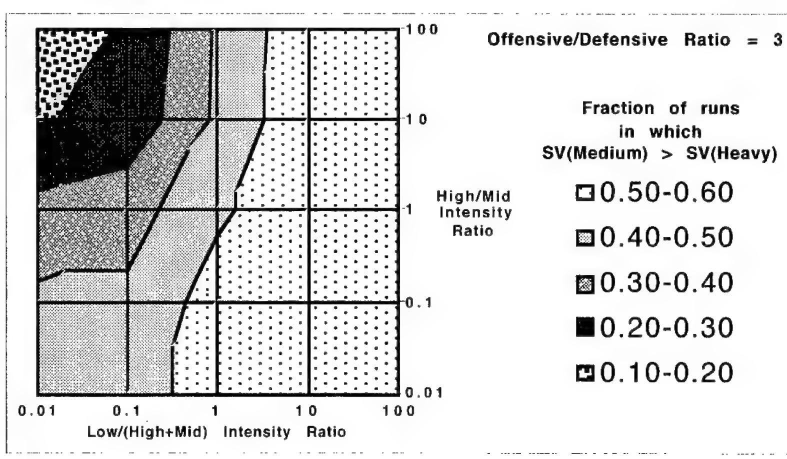
The near-term results of the descriptive analysis highlight important differences between heavy and medium-weight forces. The medium and heavy options, which represent forces that are similar to those that exist today, or could be constituted from existing systems, vyed for first place in every mission. Because of its superior deployablity and sustainability, medium was more effective than heavy around 60 percent of the time in the two low-intensity missions, protect and stabilize. Medium was also preferred to heavy by about the same margin in the Small Scale Interventions scenario, where these missions are the most prevalent. In the high-intensity, offensively-oriented evict mission, however, heavy was very strongly preferred over medium, beating it over 90 percent of the time. Not surprisingly, medium beat heavy less than a quarter of the time in the Major Regional Contingencies scenario, which emphasizes the evict and halt missions. Heavy was also more effective than medium in the halt and defend missions, winning 70 or more percent of the time, but in the raid mission, it was only able to win a very slim majority of the time. Accordingly, in the Balanced Mix of Contingencies scenario, where all six missions are given equal weight, medium was preferred to heavy just over 40 percent of the time.




(a)




(b)




(c)

**Figure 11.14. Strategic Value Preference Surface for Medium over Heavy in the Near Term when: (a) defensive missions are more important; (b) offensive and defensive missions are equally important; and (c) offensive missions are more important.**

Figure 11.14 shows how the preference frequency for medium over heavy varied across different types of futures. The prevalence of the various missions changes across this space: defensive missions are more prevalent in the first slice, while offensive missions are in the last slice; and high-intensity missions are most prevalent in the upper left corner of each slice, mid-intensity missions in the lower left corner, and low-intensity missions on the right side.

In the far term, future medium was always the best option, and advanced air only was almost always the worst option, in every mission, with lean heavy, advanced air + SOF, and enhanced light all competing for the three middle positions, ending up in that order most of the time. The only time that future medium's lock on first place was broken was by lean heavy when it shifted its mix of operational concepts quite drastically from almost 60 percent maneuver warfare to 75 percent ambush/envelopment, while future medium continued to use its broad baseline mix of concepts. Even this dramatic shift only enabled lean heavy to make significant inroads in the high-intensity, offensively-oriented evict mission, where it still only won about 40 percent of the time. These gains would certainly have been lost if future medium also used the same mix of concepts.

The various input perturbations featured in the exploration phase provided some useful insights into the sensitivity of the results in each time frame. The following perturbations all had a similar impact, favoring medium over heavy in the near term, and advanced air + SOF over lean heavy in the far term.

- *Using the convex value function for self-sufficiency, instead of linear.* Widened gaps in self-sufficiency between systems with high and low-to-moderate ratings, favoring options that were already ahead on this characteristic.

- *Increasing the importance of deployability relative to ability to shock and survivability in the protect mission.* Changed distribution of importance among attributes from a fairly even mix to one where deployability is clearly the most important, favoring lighter force options.

- *Decreasing the direct contributions of ability to support, economy and coordination to deployability.* Realigned the characteristic importance weights for deployability, making transportability and self-sufficiency, the two key system characteristics for this attribute, much more important, favoring options with systems that rate highly on them.
- *Decreasing the importance of transportability for systems playing air roles.* Reduced the contribution of air systems to force-level transportability, favoring options with lighter, ground-based systems.

Viewed together, these changes and their effects have a clear message: shifting to lighter ground vehicles may actually be even more crucial that it already appears to be. Reducing the importance of air roles would shift more of the burden of providing force-level transportability onto ground systems. Making transportability an even larger contributor to deployability would further increase the importance of vehicle size and weight. Changing the value function for self-sufficiency to convex would also reward lighter vehicles, since they are usually also more fuel-efficient, and easier to maintain. Finally, raising the relative importance of deployability for the low-intensity protect mission would amplify the effects of the other changes for this mission to make going to lighter fighting vehicles the most direct way to improve effectiveness.

## 11.4 OBSERVATIONS REGARDING ARMY POLICY CHOICES

The Army is currently in the midst of what promises to be a historical transformation, which aims to create a new blend of forces that will enable it to achieve "strategic dominance across the entire spectrum of operations" (Shinseki, 1999). To reach this goal, the Army envisions that it will evolve through three stages: the current "legacy force," an "interim force," and a final "objective force." The legacy force encompasses all of the existing heavy and light formations, while the interim force provides some type of responsive, medium-weight option in the very near future, serving as a bridge to the objective force,

evolving over time to absorb and integrate new technology. Several observations regarding the policy choices facing the Army can be drawn from the insights discussed in the preceding section. These observations are discussed below, beginning with the objective force of the future, continuing with the interim force, and concluding with the legacy force in use and under development today.

## Objective Force

*Be careful not to over-design Future Combat System.* The notional version of the FCS used in this analysis may be more capable than is really necessary. Aiming too high might actually be detrimental, in terms of the excessive cost and the extra time it would take to develop and field such a sophisticated system. It may be more sensible to scale back the capabilities envisioned for the FCS to the point where an FCS-based medium-weight force would be on a par, or even somewhat less effective than a modernized heavy force in its forte, the evict mission, but superior to it in most—not necessarily all—situations for every other mission. Over time, if the need for a specialized evict capability diminishes, the capabilities of the FCS could be augmented enough for it to take over this mission as well. In the meantime, however, the FCS can get away with less.

*Keep characteristics of Future Combat System balanced.* Even if the capability objectives of the FCS are scaled back a bit, every effort should be made to maintain the balance among its characteristics. In particular, protection should not be given short shrift, even if this means that firepower or other characteristics have to be reduced. This is especially true if heavy armor forces will be available for the highest-intensity missions, and the FSC-based medium-weight forces are primarily intended for use in low-to-mid-intensity missions, where deployability and survivablity are more important than lethality and the ability to shock. This balance will ensure that the medium-weight objective force is robust, and less susceptible to the impact of uncertainties on the battlefield, since it will be less vulnerable if surprised by the enemy, and less dependent on complex interactions with other force components for its survivability.

*Use Comanche reconnaissance attack helicopter to complement Future Combat System.* This RAH-66 can make the medium-weight objective force more effective, and more robust, especially in low-intensity situations. This system's flexibility and elusiveness in an aggressive reconnaissance role enable it to contribute disproportionately to the transportability and stealth of this force, making it more deployable and more survivable as a whole. The early presence and effective, adaptive reconnaissance that the RAH-66 provides on the ground will tend to complement the FCS, especially if its capabilities are scaled back.

*Develop operational concepts based on ambush and envelopment tactics.* These tactics appear to have a number of advantages, especially for an advanced medium-weight force designed around the FCS and the RAH-66. If nurtured and developed into a coherent operational concept, ambush/envelopment will have a balanced mix of characteristics that contribute to both deployability and survivability. The economy and coordination that this concept fosters will improve both of these attributes, while the its ease of support will increase deployability and its superior awareness it provides will raise survivablity.

**Interim Force**

*Give interim medium-weight vehicle substantial protection.* Hand-held anti-tank guided missiles and medium-caliber APC guns are likely to be quite prevalent in low-to-mid-intensity operations, even in the near term (Gander, 1997). Without adequate protection against these threats, an interim vehicle will be vulnerable to surprise attacks. The Army should invest in lightweight on-board or add-on defenses, like automated countermeasures, active protection, and reactive armor, which can be tested and refined on the interim vehicle, and then improved before being integrated into the FCS for the objective force.

*Use signature management, camouflage, concealment and deception to improve stealth.* Even with better defenses, the interim medium-weight vehicle is still vulnerable to direct fire, so it should temper this protection with an equal

measure of stealth. To accomplish this, the size, profile and signature of the interim vehicle should be minimized, within relevant constraints, such as cost and availability. Investments should be made in technologies that would reduce or mask the electromagnetic and acoustic signatures of the interim vehicle, and could then be developed further for application to the FCS. Tactics should also be developed for the interim force that would conceal its presence, and deceive the enemy regarding its size, disposition and intent.[79]

*Use Apache in reconnaissance role that Comanche will eventually play.* Even though the AH-64D is not ideally suited to playing the reconnaissance attack role that the RAH-66 is designed for, having the interim force use it in this role serve two purposes. First, it will take advantage of the A-64D's strengths, especially its transportability and stealth, to improve the overall survivability of the interim force. Second, this role change will encourage experimentation in the interim force, and enable it to learn how to use this type of reconnaissance asset. The experience gained in the process can then be applied to the RAH-66 when it enters goes into service, thereby smoothing its transition into the objective force.

### Legacy Force

*Allow heavy units to focus on high-intensity offensive missions.* The Abrams main battle tank, the Bradley fighting vehicle, and other heavy armored vehicles are still very potent and valuable systems. They are especially effective in the most challenging, offensively-oriented high-intensity missions, as the Desert Storm offensive in the Persian Gulf showed so clearly in 1991. As the interim force begins to take shape, however, the heavy units built around these systems should immediately be relieved of the burden of performing and supporting peacekeeping operations. Over time, the responsibility for other low-intensity

--------

[79] This is consistent with current U. S. doctrine on deception in military operations (U. S. Joint Chiefs of Staff, 1994).

missions should gradually be assigned to the new medium-weight units at the heart of the interim force.

*Rely more on pre-positioning, while continuing to modernize.* The heavy armor formations of the U.S. Army act as a deterrent to aggression, and an insurance policy in case deterrence fails, especially in the Persian Gulf, Korea, and even Europe. Since high-intensity conflicts are most likely to occur these regions, where U.S. interests are clearly at stake, heavy units should be stationed nearby in areas where they can reside and train for these missions, or have their equipment pre-positioned so that they can be deployed quickly if tensions rise (Gritton et al., 2000). These units should continue to modernize, retiring or upgrading old models and variants that are obsolete, or can be replaced by new interim systems. These improvements should also concentrate on technologies that are transferable to the objective and interim forces.

*Acquire only enough Crusaders to meet objective force requirements.* The Crusader artillery and re-supply system is highly potent and extremely capable, but it is also very heavy (Matsumura, Steeb and Gordon, 1998). As such, it does not fit in with the current Army vision for a lighter, more strategically agile force. Thus, only enough of these systems should be acquired to meet the limited needs of leaner, specialized heavy units that are retained in the objective force exclusively for high-intensity missions.

*Enhance light units to complement heavy and medium-weight units.* The highly capable light units of the U.S. Army have traditionally supported heavy units in high-intensity operations. They should continue play this role, where necessary, but should also be enhanced so that they can be more easily integrated into medium-weight units, taking on a primary role certain specialized aspects of peace enforcement, such as urban operations. These enhancements should include greater mobility and protection, as well as more varied training that includes joint exercises with new medium-weight units.

## 11.5 PUTTING THIS DISSERTATION INTO PERSPECTIVE

These observations illustrate how insights gleaned from an analysis using the HIMAX process can inform key policy choices. Even though the analysis conducted for this dissertation is only a demonstration, the particular insights it generated are clearly relevant to the key choices facing the Army today. More importantly, the observations drawn from these insights involve crucial, multi-million-dollar decisions regarding research, development, acquisition, and training, which will determine the effectiveness and versatility of U.S. forces in the future. This indicates that the HIMAX process can inform, and thus improve, high-level decision making in the defense planning arena. Of course, to provide reliable and effective support at this level, such analysis must involve top-notch experts, and its results must be integrated with those of detailed simulations and extensive field trials. Thus, if applied appropriately, the HIMAX process could potentially become a vital component of the support infrastructure for major Army force restructuring decisions.

What are the other important contributions of this dissertation, and the HIMAX technique, beyond this specific example? First, the custom evaluation model at the heart of this demonstration could easily be adapted to compare other types of military force options in a variety of contexts. By quantifying the tradeoffs among key force attributes, and linking them to concrete characteristics of force components, this model can assess the effectiveness of different force options across a spectrum of missions, and then compare their overall strategic value in a wide range of alternative futures. More generally, the HIMAX process combines multiple objectives, compares diverse options, captures synergistic interactions, represents uncertainty explicitly, and explores the implications of divergent minority opinions. This unique combination of features enables the HIMAX process to assist high-level policy makers in making better decisions.

# 12. THE FUTURE OF HIMAX

This dissertation has introduced and demonstrated the HIMAX process as a new and effective way to structure and analyze complex policy choices. This novel approach represents a substantial improvement over traditional methods, particularly in terms of flexibility and breadth. This final chapter reviews the advantages of the HIMAX methodology, together with its limitations, considers several possible improvements, and suggests a few promising candidates for future policy applications.

## 12.1 ADVANTAGES AND LIMITATIONS OF HIMAX

The HIMAX process provides a unique combination of capabilities that can be extremely valuable for structuring and evaluating high-level policy choices in a context that is characterized by complexity and uncertainty. American defense planners face exactly this type of situation today; if current trends continue, future U.S. forces—Army forces in particular—will frequently have to respond rapidly to diverse conflicts around the world, often in unique and complex circumstances. This sort of future is inherently uncertain, so it is extremely difficult to anticipate the challenges it will pose, and then design a force that is robust and versatile enough to address them.

To be useful in this context, an innovative approach to force evaluation should: capture synergistic interactions; reconcile competing objectives; compare diverse options across multiple missions; represent uncertainty explicitly; and explore—rather than ignore—implications of divergent minority opinions. This section discusses the advantages and limitations of the HIMAX process with regard to each of these five key capabilities, which it was designed to integrate.

## Capture Synergistic Interactions

The HIMAX evaluation model captures synergies in two ways. First, the system role importance ratings allow combinations of different types of systems, like vehicles or aircraft, to contribute more to some characteristics of a force than others. This captures synergies among the systems because it allows them to complement one another by having their best characteristics count more than their weaker ones. In this demonstration analysis, for example, reconnaissance roles emphasized stealth, while direct-fire roles emphasized protection. Thus, if stealthy reconnaissance systems and better-protected direct-fire systems are used together, the synergy between them will improve overall force effectiveness. These role importance ratings worked very well in this demonstration; the experts used every possible level, and often gave similar responses, indicating that they understood the rating scale, and were using it consistently.[80]

The HIMAX evaluation model also allows synergistic interactions between system and operational characteristics to contribute to the attributes of a force. This captures the *added* benefit of having higher levels of both characteristics. For example, most of the experts in the demonstration gave the highest rating, extremely important (9), to the contribution that interactions between the self-sufficiency and ability to support of a force make towards its deployability and sustainability, the two attributes associated with power projection. Including these synergistic interaction ratings had subtle, but sometimes quite significant effects. For example, somewhat higher ratings for the interaction of firepower with a few operational characteristics, especially economy, gave it a larger contribution to survivability than mobility, even though both characteristics received the same rating for their direct (i.e., main effect) contribution.

--------

[80] On the 0-to-9 importance scale, the aggregate ratings ranged from weak (2) to extremely strong (9), and some characteristics were always rated a lot higher than others in every one of the nine roles (see Table 6.7).

Because there are so many of these synergistic interaction ratings, however, assessing all of them can be a fairly tedious task for the experts—one of the participants in the demonstration even declined to do them—so they may not put the same degree of thought into every assessment. In this case, the aggregate ratings were generally consistent, although a few individuals systematically gave higher responses than others. Such biases, resulting from fatigue or disinterest, could be reduced by splitting up the assessments among the experts, or having them do their ratings in a different, randomly assigned order.

### Reconcile Competing Objectives

The HIMAX evaluation model determines the overall effectiveness of an option from its attributes, which represent high-level objectives. The importance of these attributes may vary considerably from one situation to the next, so they can be weighted differently for each mission in a broad spectrum of possibilities. For each mission, the experts make pair-wise assessments of the attributes, which are used to determine the corresponding attribute weights.[81] The distribution of these weights was quite different for each mission, indicating that the HIMAX approach can use expert inputs to quantify the relative importance of competing objectives across a range of situations.

There were, however, a few problems associated with this feature. First, if there is a lot of disagreement among the experts, such as in the protect mission in this analysis, aggregation can push all of the ratings towards one, thereby giving nearly equal weights to all of the attributes. This suppresses the diversity of the experts' assessments, but also encourages a robust mix of attributes, which is appropriate because there is no consensus on which of them are more important. Second, the experts have to repeat the necessary pair-wise assessments for every

--------

[81] The rating scale used for these assessments, and the technique used to determine the attribute weights from them, are both described in Chapter 3. This approach is based on the AHP, which is described in detail by Saaty (1980).

mission—fifteen for each of the six missions, in this case, since there are six attributes—so if there are too many missions or attributes, fatigue could set in and the experts might devote less attention to some of their assessments. The consistency of the experts' responses indicates that this was not a major problem in this analysis. Lastly, to ensure that the aggregate ratings are integers, the evaluation model uses the lower of the two middle responses when there are an even number of respondents, as was the case in this analysis. This approach induces a bias that favors the attributes at the end of the order (sustainability, survivability, etc.) over those at the top of the order (deployability, lethality, etc.).[82] This bias is not a major concern, however, because the controversial perturbations identified and examined in the exploration phase involve even larger deviations from the baseline ratings.[83]

### Compare Diverse Options Across Multiple Missions

The HIMAX process can evaluate and compare the effectiveness of multiple options in several different missions at the same time. In this demonstration, five options were considered in each time frame, for six different missions. These options span a wide range of diverse force configurations, while the missions span a broad spectrum of operations. The analysis quantitatively compared the options across every mission, deriving mission effectiveness from concrete differences in the option characteristics. The noticeable variations in these outcomes, and the genuine insights they produced, indicate that HIMAX provides an effective way to inform high-level policy choices.

--------

[82] For example, if four experts rate the importance of deployability relative to sustainability as 1, 2, 3 and 4, a value of 2 will be assigned to this rating. If they rate sustainability relative to deployability their responses would be 1/4, 1/3, 1/2 and 1, and the aggregate rating would be 1/3. Thus, in this case, deployability would be given more weight if the order of the attributes in this rating was reversed.

[83] If the integer requirement is relaxed, this bias could be eliminated by using the geometric mean since, as Saaty (1989) explains, this retains the symmetry of the reciprocal rating scale.

Of course, more options and missions could be added. If the extra options include new systems or operational concepts, then the characteristics of these components would have to be specified with new rating distribution estimates. Conversely, no such estimates would be necessary if the added options consist entirely of components that are already in the other options. But, if these new options are too similar to the existing ones, they could clutter the analysis and create more confusion than insight. Adding missions would make the HIMAX process more complex, and would require more assessments from the experts. New missions would have to be incorporated in the parameterization scheme used in the prioritization phase, which would complicate this aspect of the analysis. And, for every additional mission, the experts would have to assess one more set of attribute ratings, consisting of fifteen pair-wise comparisons in this case. Thus, only sensible changes in the set of options under evaluation should be considered. For example, introducing a few medium-weight force options that include a mix of new and existing components, while considering the same six missions, would require a modest amount of additional effort, but could provide some insight into more subtle differences among this important class of options.

### Represent Uncertainty Explicitly

Uncertainty is included explicitly at two points in the HIMAX process; technological and situational uncertainty is represented probabilistically in the characteristics of option components, while strategic uncertainty is examined parametrically in the prioritization phase. The characteristics of each option component are represented by discrete, three-level probability distributions[84], which are intended to capture uncertainty due to situational factors, like terrain

--------

[84] Option components are defined by assigning them a median rating for each system or operational characteristic, and probabilities that the rating is actually one level higher, and one level lower. For example, if a system is assigned a median rating of 5, a plus one probability of

and weather, together with technological risk. Estimating three-level probability distributions for the system and operational components of every option requires a considerable amount of time, effort and research prior to the analysis. While the estimates used in the demonstration were somewhat speculative, especially for the far term systems, they did provide a reasonable indication of the impact that this sort of uncertainty can have on mission effectiveness. For example, the range of effectiveness was largest for the air only option, in both time frames, because the firepower, stealth and self-sufficiency of its systems, and every characteristic of its only operational concept, standoff (no ground information), were all highly uncertain.

This uncertainty in effectiveness serves another important function. If the distributions for some options overlap, their effectiveness can be compared in every Monte Carlo run to determine how often an option is preferred to another. Such preference frequencies provide a better indication of how close options are to one another than the amount of overlap. This is also true for comparisons in the prioritization phase, where mission importance is parameterized to represent strategic uncertainty. The surfaces constructed in this phase show how option preferences change across a space of alternative futures. The parameter values dictate where on this surface a particular future lies, and the contours indicate the normalized preference frequency.

In this demonstration, such plots proved to be an effective way to illustrate the impact of strategic uncertainty on overall option preferences. For example, this type of visualization showed very clearly that, in the near term, a medium-weight force would have a clear but modest advantage over a heavy armored force in futures where low-intensity missions are the most important, while a heavy force would be superior in futures dominated by more offensive high-intensity missions. Of course, these pictures can be hard to comprehend initially,

---

0.2, and a minus on probability of 0.3, then its discrete probability distribution is 0.3 for 4, 0.5 for 5, 0.2 for 6, and 0 for every other level.

and after seeing multiple versions they can start to look the same. Perception difficulties like these may be reduced somewhat by using three-dimensional color representations.

This use of uncertainty, however, has one important weakness: the characteristic distribution estimates for option components. While well-reasoned in this analysis, such estimates are always speculative, since they incorporate numerous unknown factors. Nonetheless, they serve an important purpose: to generate insights by showing how uncertainty influences effectiveness. The outcomes of the HIMAX process are obviously sensitive to changes in the underlying component characteristic distributions, so in future analyses, it would be prudent to give these estimates a more credible basis, and explore the impact of systematic changes in them.

### Explore Implications of Divergent Minority Opinions

The most salient feature of the HIMAX process is its ability to identify minority responses that differ most substantially from the consensus ratings, and then examine the impact they would have on the evaluation and prioritization results. In the demonstration analysis, this kind of exploration produced some interesting, and quite useful insights. Specifically, large changes that raised the importance of land systems for transportability, increased the contribution of transportability to deployability, or made this attribute more important in the protect mission, improved the standing of medium relative to heavy in the near term. Such controversial changes represent plausible dissenting opinions that are worth considering because of their potential influence. The interpretation of the baseline results should reflect the implications of these opinions; if they pull in a certain direction, the results should be presented with a corresponding slant. For example, in the baseline of the demonstration analysis, deployability and survivability were equally important for the protect mission, but dissenting opinion indicated that deployability might actually be a bit more important, so this attribute was given somewhat more attention in the prescriptive analysis.

The method used to find such interesting combinations of rating changes, however, was very tedious and time-consuming. While the calculations were automated, the search was not. There were too many possible combinations of rating changes to try all of them, so the search was limited to large deviations based on responses from the same expert, and related combinations of small changes that were the most influential on their own. This process worked fairly well, identifying several very interesting sets of changes. Nonetheless, the search required considerable effort and concentration, and it is still possible that other equally interesting perturbations were missed. Thus, in future applications, it would be better to use a more comprehensive, systematic search technique that automatically screens the results to find the most interesting changes.

## 12.2 POSSIBLE IMPROVEMENTS

The preceding discussion pointed out several important limitations of the HIMAX process. Thus, there are many aspects of this new approach that, if changed or extended, could make it easier to use, or improve the information it provides. A number of possible improvements came to light while the HIMAX methodology was being developed, or in the course of its demonstration. Some of these are changes specific to this particular application, while others extend or alter the methodology, or how it is implemented, in a more general way.

### Specific Changes

*Use fewer system roles*. The aggregate ratings of system role importance for each characteristic were very similar for the four related pairs of roles: direct fire attack and support; indirect fire close and far; close air support and deep air interdiction; and reconnaissance scout and strike. (The largest difference in ratings was just 3 intervals, for firepower in the two reconnaissance roles.) This indicates that the number of roles used in the analysis could be reduced to five—direct fire, indirect fire, air attack, reconnaissance, and special operations—without changing how systems playing different roles complement one another

in a force. This would reduce the number of assessments the experts make for this set of ratings by 24, or almost half. Presumably, the experts would rate the single merged role about the same as one of the two original roles, or somewhere in between, which would have little if any effect on the results of the analysis.

*Allow options to use operational concepts in different proportions for each mission.* The customized force-evaluation version of the HIMAX model is currently structured to assign each option a single set of operational concept proportions, which are used to calculate its operational characteristics in every mission. It is conceivable, however, that an option might use a different mix of concepts in each mission, or even just one, exclusively. For example, a ground-based option could use: standoff (w/ ground information) for halt, defend, and protect; maneuver warfare for evict; ambush/envelopment for raid; and peace keeping/ enforcement for stabilize. Mission-specific concept proportions would make operational composition of options more complicated, but the added flexibility they provide would also make the model more realistic.

*Vary relative importance of system, operational and synergistic contributions.* In the current model structure, the system, operational and synergistic contribution ratings are implicitly given the same weight in calculating the normalized characteristic weights for each attribute. This is usually a reasonable assumption, but it may be inappropriate for some attributes. In calculating survivability, for example, system contributions might be twice as important as operational ones, and three times as important as those due to synergistic interactions. Adding just three more expert assessments that assign weights to these three contribution sources could implement this change without much additional effort.

## General Extensions

*Weight experts' assessments according to their degree of expertise.* Currently, the assessments made by all of the experts are treated the same, and the median response is used as the aggregate value for each rating. This approach does not

consider the amount of relevant expertise an individual experts has for each assessment; an expert may be well-qualified to assess one type of rating, yet ill-prepared for others. To account for such differences, the model could weight expert's assessments according to the extent of their relevant expertise. This would take advantage of diversity among the experts, and avoid focusing exploration on divergent responses rooted in ignorance or misunderstanding, rather than a well-founded difference of opinion. This logic could even be taken a bit further, assigning specific sets of assessments to certain experts based on their area of expertise, and not assigning those assessments to others. Then the experts would only provide inputs for areas that they know well, so they could spend more time on these assessments, and avoid getting bored or frustrated with other assessments in areas that they know less about.

*Apply mission-specific thresholds to option characteristics.* The current HIMAX evaluation model does not incorporate special mission requirements that might place constraints on certain characteristics. For example, in this demonstration, the evict mission might require a minimum level of protection that cannot be compensated for by other force characteristics. Such requirements can be incorporated by applying thresholds to each characteristics that are different for every mission. If a thresholds is not met then the effectiveness for that mission would be lowered to zero, or possibly in proportion the extent of the violation, if the characteristic value is close to the threshold. Applying these constraints as part of the evaluation model would allow their effects to be observed and considered in the later phases of the HIMAX process. This model feature was tested during the demonstration, but the experts found the thresholds difficult to comprehend, much less assess. The threshold values suggested by the experts were inconsistent, and too high (none of the options exceeded all of them), so this feature was not included in the analysis. To account for mission-specific constraints in future HIMAX applications, an improved implementation of this technique, one that is simpler and easier to use, would have to be developed and integrated into the evaluation model.

## Future Work

*Compare strategic value to total cost in prioritization phase.* The force options under consideration may differ substantially in their total cost, including the effort required to develop, field and support them. For example, an existing heavy armored force would incur almost no *extra* cost and require little, if any, additional development, while a new medium-weight force could be quite costly, in terms of acquisition expenditures, as well as disruption and reorganization. Such cost estimates are very difficult to make for military force options, so this demonstration of the HIMAX process focused on quantifying effectiveness. If such estimates were available for all the options, they would be compared to strategic value in an essential final step of the prioritization phase. These comparisons could be shown as plots of strategic value (in a given future scenario) versus cost, with an efficient frontier drawn in.

*Automate search procedure in exploration phase.* In the demonstration analysis, a multi-stage search compared, filtered and selected interesting perturbations and option alterations during the exploration phase. While this process was tedious and time consuming, it was still far from exhaustive. A more thorough, efficient and reliable automation of this exploration procedure would make the HIMAX process much easier to use. This automation algorithm would have to mimic the human selection process, looking for controversial or influential discrepancies that have a significant impact, and then putting them together in combinations that are based on similar responses from the same experts, and involve the same missions, attributes or characteristics. If automated exploration proves to be both feasible and reliable, it would greatly increase the power and efficiency of the HIMAX process by drastically reducing its turnaround time, allowing earlier and more extensive interaction with experts or decision makers.

*Structure interaction phase to revise assessments and refine options.* Additional work is needed to further develop the HIMAX interaction phase and determine its exact structure. These efforts should focus on: understanding where and how interaction fits into the overall process; encouraging useful feedback from the

experts; screening and incorporating this feedback; and avoiding systematic biases due to gaming or championing by the experts. Of course, too much interaction may be counterproductive, both because of the time it consumes and the opportunity it creates for the experts to try to influence the results. Thus, the benefits of different modes of interaction should be compared to their drawbacks before one is selected for a particular application. This may require quite a bit of empirical testing, with both qualitative and quantitative evaluations, as well as a lot of trial and error—interactive analysis can be more of an art than a science. The lessons learned from numerous applications and critiques of the Delphi Method (Adler and Ziglio, 1996; Linstone and Turoff, 1975; Sackman, 1975), and other interactive approaches to decision modeling and strategy evaluation, should provide ideas and guidance for the design of the interaction phase of the HIMAX process.

*Develop a web-based user interface for HIMAX.* While the HIMAX process was implemented in a computer program (Analytica™), the expert assessments used in the demonstration were elicited off-line, and then entered into the program for the analysis. The whole HIMAX process would, however, be much more user-friendly and streamlined if it had a web-based interface that the participating experts could use to provide their assessments. This interface could include links to: descriptions of the HIMAX phases; definitions of the roles, characteristics, attributes and missions; detailed instructions on how to perform the assessments; and even sample outcomes based on an individual's inputs. The experts could also use this interface during the interaction phase to examine the results of the group analysis, including the exploration findings and the prioritization comparisons, before reviewing their initial assessments, revising them where appropriate, and even suggesting changes in some of the options. This sort of web-mediation would increase the efficiency and flexibility of the HIMAX process, create opportunities to improve the visual representation of its results, and enable new modes of interaction with and among the experts.

## 12.3 IDEAS FOR FUTURE APPLICATIONS

### Military Force Evaluation

Considerable effort went into customizing the HIMAX process for the evaluation of military force options. In particular, the set of characteristics and attributes developed for this demonstration is itself a significant contribution to the field of defense analysis. This customized model could, therefore, be applied quite easily to other similar sorts of force evaluation problems. One attractive possibility would be to assess and compare several of the medium-weight force options that are currently being considered by the Army for its interim force. A current heavy armored force could also be included to provide a baseline for the analysis. Ideally, the participants in this analysis would be the actual decision makers responsible for designing the interim force. Using the HIMAX process would enable them to compare the merits of various options quantitatively, while also giving them an indication of where members of the group are in agreement, and where their opinions diverge. By exploring the implications of influential minority opinions, they could determine which ones are most salient, and then focus their discussions on the arguments in favor and against those perspectives. They could also use the interaction phase to revise their assessments in light of any insights gained from the initial results, and make appropriate adjustments in the composition of the options, before re-evaluating them for a final comparison.

A similar customized evaluation model could also be applied to evaluate military force options for other countries. Of course, the strategic objectives of another country, and the constraints it faces, are likely to be quite different from those of the U.S. The HIMAX evaluation model would be modified for such an analysis to account for the issues and concerns that are most important for the country involved. These differences would, in part, be captured by the responses of the participating local or regional experts. Indeed, it would be very interesting

to compare the assessments of experts from different countries to see where their opinions on military tradeoffs were similar, and where they diverged.

### Critical Infrastructure Protection

Broader national security problems with significant civilian dimensions are also amenable the HIMAX process. The protection of critical infrastructures is an excellent candidate because it involves multiple, competing objectives, including security against terrorism, personal privacy, and economic growth. There is also tremendous uncertainty regarding the threats posed to critical infrastructures, the consequences of different types of attacks, and the effectiveness of possible protection strategies. (Marsh, 1997)

By treating uncertainty explicitly and combining multiple objectives, the HIMAX approach would help decision makers in both government and the private sector get their mind around this problem, and understand the tradeoffs associated with alternative strategies for dealing with it. This approach would also allow experts from very different communities to see where and how they agree or disagree with each other, and explore the impact of their differences in opinion on the results of the analysis. Applying HIMAX to critical infrastructure protection should provide policy makers with useful insights, and aid them in designing solutions that are both effective and politically viable.

### Mars Exploration and Research

The failures of the Mars Global Surveyor and the Mars Polar Lander in late 1999 brought Mars exploration to the forefront of public attention. The debate surrounding these incidents has, naturally, centered on the oversights and mismanagement that ultimately caused the failures. A more interesting long-term question, however, has been lost in the controversy: what is the right sequence of missions that the National Aeronautics and Space Administration (NASA) should be planning for the coming decades? Obviously, solving the current problems with mission management and budgeting are an important

part of addressing this question, since they relate to the reliability of future missions. The real crux of this question, however, lies in understanding and balancing the underlying objectives of the Mars exploration architecture (Elachi, 1998). These objectives are mostly scientific, but also include other national goals, like maintaining prestige, and fostering technological innovation. The scientific objectives of Mars exploration are numerous, and often contested, ranging from searching for signs of life, to learning about the planet's geological history, to gaining a better understanding of its atmosphere and climate.

The HIMAX process could be used to evaluate alternative Mars exploration strategies based on inputs from NASA decision makers, scientists studying Mars, spacecraft engineers and other experts. This could provide provocative insights that could inform important high-level policy choices regarding the restructuring of Mars exploration strategy. The structure of the HIMAX process would force the participants to make tradeoffs among the key attributes of various strategy options, and allow them to explore the implications of controversial minority opinions. Since all of the uncertainties would be included in this analysis explicitly, their effects on option preferences could also be observed, and taken into account. A dynamic element could be added to the model to represent the effectiveness of adaptive strategies, which use the experience and knowledge gained as the program unfolds to guide and shape subsequent missions.

## 12.4 FINAL THOUGHTS

This dissertation demonstrated a new way for high-level decision makers to structure expert advice and inform complex and uncertain policy choices. This new HIMAX approach combines exploratory modeling with MADM to provide perspectives, insights and observations that conventional methods might miss. In particular, it uses the diversity of expert opinions to guide exploration, rather than relying on group consensus alone. This dissertation is, therefore, a unique and important contribution to the field of strategic decision support.

# APPENDIX A. OPPOSING FORCES USED IN EVALUATION MODEL

This appendix describes the characteristics assigned to the opposing forces for each mission in the near-term and far-term portions of the analysis, and then discusses the resulting attributes of these forces. These opposing force attributes determine a floor level of effectiveness for each mission—the zero-value of the normalized effectiveness scale that the options in the analysis are compared on. This calculation process is described in Chapter 3, and these effectiveness results are presented in the Chapter 8.

## A.1 ASSIGNMENT OF CHARACTERISTICS TO OPPOSING FORCES

The characteristics of an opposing force represent its inherent properties at an aggregate level, which can differ across missions. In this analysis, there are three basic types of opposing forces in each time frame, representing heavy, mechanized and light enemy forces. For both time frames, the opposing force is heavy in the halt and evict missions, mechanized in the defend, protect and raid missions, and light in the stabilize mission. But, the characteristics of these opposing forces differ in the two time frames, reflecting the impact of technology proliferation and other factors. These assignments are, however, only generic estimates of the capabilities of enemy forces the U. S. may face in future conflicts. They are only intended to provide a floor for the effectiveness measure, not a precise characterization for a specific engagement.

The opposing force characteristics for each mission in the near term are shown in Table A.1. The differences between the three types of opposing forces are quite clear. The heavy opposing force has more firepower and protection than the other two force types, but its levels of transportability, stealth and self-sufficiency are quite a bit lower. On the operational side, it also has slightly less awareness, adaptability and ability to support than either of the other two types

of opposing forces. The light opposing force has almost the opposite strengths and weaknesses. It has by far the highest of transportability, stealth and self-sufficiency of all three force types, but it also has the lowest levels of mobility, firepower and protection. Operationally, the light opposing force excels in adaptability and ability to support, but is less well-coordinated and economic than the other force types. The mechanized opposing force falls between heavy and light on most characteristics, although it does have more mobility than either of them, and just as much awareness and coordination. There is, however, a small differences between the heavy opposing forces in the halt and evict missions; the halt opposing force has slightly more mobility. Also, the mechanized opposing force in the defend mission has a bit more economy than those in the protect and raid missions.

**Table A.1**

**Opposing Force Characteristics in Near Term**

| Opposing Force: | Heavy | Mech. | Mech. | Heavy | Mech. | Light |
|---|---|---|---|---|---|---|
| | **Opposing Force Ratings for Each Mission** | | | | | |
| **Characteristic** | Halt | Defend | Protect | Evict | Raid | Stabilize |
| *System* | | | | | | |
| Transportability | 3 | 5 | 5 | 3 | 5 | 8 |
| Mobility | 4 | 4 | 4 | 3 | 4 | 2 |
| Firepower | 5 | 4 | 4 | 5 | 4 | 3 |
| Protection | 3 | 2 | 2 | 3 | 2 | 1 |
| Stealth | 2 | 4 | 4 | 2 | 4 | 8 |
| Self-sufficiency | 3 | 5 | 5 | 3 | 5 | 7 |
| *Operational* | | | | | | |
| Awareness | 3 | 4 | 4 | 3 | 4 | 4 |
| Coordination | 4 | 4 | 4 | 4 | 4 | 3 |
| Adaptability | 3 | 4 | 4 | 3 | 4 | 6 |
| Economy | 4 | 4 | 3 | 4 | 3 | 2 |
| Ability to Support | 4 | 5 | 5 | 4 | 5 | 6 |

Heavy, mechanized and light opposing forces are assigned to the same missions in the far term, except that there are no differences among the heavy or the mechanized opposing forces in this time frame. The characteristics of the opposing force for each mission in the far term are shown in Table A.2. As in the near term, there are significant differences among the three opposing force types.

The light opposing force again has substantially more transportability, stealth, self-sufficiency and adaptability than the other two force types, plus a little more ability to support, and it still rates much lower on mobility and protection, but it is now about even or just a bit behind the mechanized opposing force on firepower, awareness, coordination and economy. Similarly, the heavy opposing force is still the worst of the three types for transportability, stealth, self-sufficiency, adaptability and ability to support, and remains the best for firepower, protection and economy. The mechanized opposing force still falls between the other two force types on most characteristics, and is now only even with heavy for the highest levels of mobility, awareness and coordination.

**Table A.2**

**Opposing Force Characteristics in Far Term**

| Opposing Force: | Heavy | Mech. | Mech. | Heavy | Mech. | Light |
|---|---|---|---|---|---|---|
| | **Opposing Force Ratings for Each Mission** | | | | | |
| **Characteristic** | Halt | Defend | Protect | Evict | Raid | Stabilize |
| *System* | | | | | | |
| Transportability | 3 | 5 | 5 | 3 | 5 | 8 |
| Mobility | 4 | 4 | 4 | 4 | 4 | 2 |
| Firepower | 6 | 4 | 4 | 6 | 4 | 4 |
| Protection | 4 | 3 | 3 | 4 | 3 | 1 |
| Stealth | 2 | 4 | 4 | 2 | 4 | 8 |
| Self-sufficiency | 3 | 5 | 5 | 3 | 5 | 7 |
| *Operational* | | | | | | |
| Awareness | 4 | 4 | 4 | 4 | 4 | 4 |
| Coordination | 5 | 5 | 5 | 5 | 5 | 4 |
| Adaptability | 3 | 4 | 4 | 3 | 4 | 6 |
| Economy | 5 | 4 | 4 | 5 | 4 | 3 |
| Ability to Support | 4 | 5 | 5 | 4 | 5 | 6 |

## A.2 ATTRIBUTES OF OPPOSING FORCES

Figure A.1 shows the attributes of the opposing forces in each mission for the near term. The small differences in the heavy and mechanized force types do have noticeable effects on the attributes of the opposing forces involved. The greater mobility of the heavy opposing force in the halt mission gives it slightly higher attribute levels than its counterpart in the evict mission, with the largest

impact on maneuverability. Similarly, because of its higher economy rating, the mechanized opposing force in the defend mission has higher attribute levels than the other two mechanized forces. Overall, the mechanized opposing forces are better than the heavy opposing forces on every attribute, especially deployability and sustainability. The light opposing force has an even higher level of deployability and about the same level of sustainability, but slightly lower levels of the other four attributes.

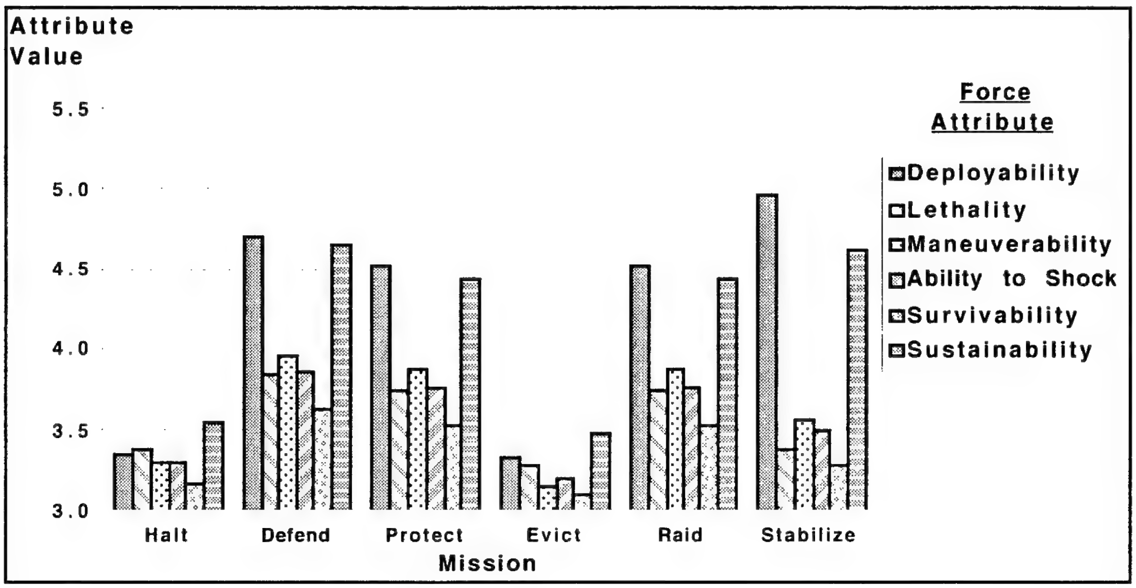



**Figure A.1. Near-Term Opposing Force Attributes**

The attributes of the far-term opposing forces are shown in Figure A.2. The three different types of opposing forces—heavy for halt and evict, mechanized for defend, protect and raid, and light for stabilize—still have noticeably different attribute values. The mechanized opposing force is still better than heavy on every attribute, especially deployability and sustainability, though less so on lethality. The light opposing force has the highest levels of deployability and sustainability, and while its other attribute levels are below those of the mechanized opposing force, they are about even with those of the heavy opposing force.

## Opposing Forces

In both time frames the heavy opposing force has the lower attributes levels than the other two force types. As a result, the floor levels effectiveness for the halt and evict missions are substantially lower than those of the other missions. Thus, the normalization process will tend to shift the effectiveness values for these two mission up relative to these values for the other missions.

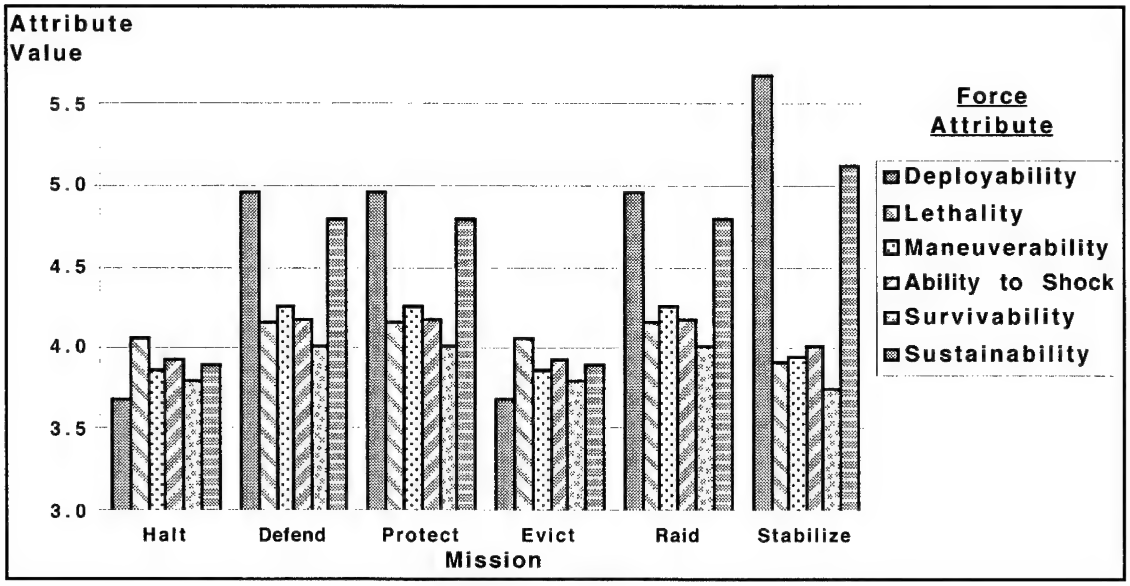



**Figure A.2. Far-Term Opposing Force Attributes**

## APPENDIX B. BIOGRAPHICAL INFORMATION ON EXPERTS

This appendix provides biographical information on the eight people who participated as experts in the demonstration analysis. These individuals were all associated with RAND—either as a member of the research staff, or as a visiting military fellow or analyst—when they provided their assessments in October and November of 1999. To protect their privacy, these experts are only identified by number, not by name, in the following discussion of their education, and their experience in the military and in defense analysis.

**Table B.1**

**Education of Participants**

| Expert | Degree | Area of Study | University/School |
|---|---|---|---|
| 1 | B.S.<br>M.S.<br>Ph.D. | International Relations,<br>Policy Analysis | West Point (USMA),<br>California State University,<br>RAND Graduate School |
| 2 | B.A.<br>M.A.<br>Ph.D. | Humanities,<br>International Relations,<br>Modern History | Princeton University,<br>Boston University,<br>University of Heidelberg |
| 3 | B.S.<br>M.S. | Mathematics,<br>Operations Research | University of Kansas,<br>Naval Postgraduate School |
| 4 | B.A.<br>M.A.<br>M.B.A.<br>Ph.D<br>(candidate) | History,<br>International Relations,<br>Business Administration,<br>Policy Analysis | The Citadel,<br>St. Mary's University,<br>Marymount University,<br>George Mason University |
| 5 | B.S.<br>Ph.D. | Aeronautical Engineering,<br>Aerodynamics | Southampton University |
| 6 | B.S.<br>M.S. (3)<br>M.M.A.S.<br>Ph.D. | Systems Management,<br>Civil Engineering,<br>Operations Research,<br>Military Theater Operations,<br>American History | West Point (USMA),<br>University of Southern California,<br>School of Adv. Military Studies,<br>Stanford University |
| 7 | B.S.<br>M.S.<br>Ph.D. | Chemical Engineering<br>(Nonlinear modeling/control) | Stanford University,<br>California Institute of Technology |
| 8 | B.A.<br>M.A.<br>Ph.D. | International Relations,<br>Political Science | University of California, Irvine |

## Biographical Information

### B.1 EDUCATION

As a group, the participants in the demonstration analysis have impressive and extremely diverse educational credentials, which are shown in Table B.1. They all have at least a masters degree, and three quarters of them have a Ph.D. The institutions they attended include specialized military, science and policy schools, as well as universities, many of which are quite prestigious. These experts have studied a wide range of disciplines, encompassing the humanities, social sciences, mathematics and engineering, in addition to multidisciplinary fields like policy analysis and management. The breadth and quality of the education received by the people in this group lend credibility to their opinions, both in the aggregate and individually.

**Table B.2**
**Military Experience of Participants**

| Expert | Active Years | Reserve Years | Service | Branch | Highest Rank |
|---|---|---|---|---|---|
| 1 | 5 | 12 | Army | Infantry | Major |
| 2 | 20 | 0 | Army | Intelligence, Military Police, Foreign Area Officer program | Major |
| 3 | 17 | 4 | Army | Armor | Major |
| 4 | 20 | 0 | Army | Field Artillery | Lt. Colonel |
| 5 | 0 | 0 | N/A | N/A | N/A |
| 6 | 22 | 0 | Army | Corps of Engineers | Lt. Colonel |
| 7 | 0 | 0 | N/A | N/A | N/A |
| 8 | 3 | 0 | Army | Airborne Infantry | Sergeant |

### B.2 MILITARY EXPERIENCE

This group of experts includes people with quite different levels of military experience, as indicated in Table B.2. Half of the experts have twenty or more years of experience in the Army, and are either still serving or retired at the rank of Major or Lieutenant Colonel. Among the remaining four participants, the military experience levels ranges from none at all, to a three-year enlisted stint, to

12 years as an Army Reserve officer (plus 5 years on active duty). Since all the experts with military experience served in the Army, their opinions as a group will tend to provide an Army-centered perspective. Each of them served in a different branch of the Army, however, so they all had quite different types of training and assignments, which should make their opinions more varied. While the other two participants do not have any military experience, they have both worked in defense analysis since completing their education. Thus, all of the participants are familiar enough with combat—albeit from different perspectives—to provide the inputs required for this demonstration of the HIMAX process.

**Table B.3**

**Defense Analysis Experience of Participants**

| Expert | Years | Organizations | Topics |
|---|---|---|---|
| 1 | 10 | Army, RAND, Office of the Secretary of Defense (Program Analysis & Evaluation) | Logistics, Infrastructure, Ground force size/composition |
| 2 | 18 | Center for Military History, Defense intelligence Agency, RAND | Future Army forces, Peace operations, War games/modeling, Special operations forces, Theater-level operations |
| 3 | 21 | Army Armor units, USMA Mathematics Professor | Tactical problem solving, Resource allocation and training |
| 4 | 23 | Army, RAND | Future Army force issues, Concepts and technologies |
| 5 | 5 | Centre for Defence Analysis, in the Defence Evaluation and Research Agency (U.K.) | Future force planning, "Blue sky" and applied research, Procurement support |
| 6 | 25 | Army, RAND | Urban Operations, Author of *Operations*, FM-100-5, Planning for 3rd Armor Division In Operation Desert Storm |
| 7 | 2.5 | RAND | Air interdiction of ground forces, Enhancing Air Force platforms, Military use of commercial satellites |
| 8 | 17 | RAND, Office of the Secretary of Defense | Air operations analysis, Air base security, Military strategy, Crisis management, Arms control |

## B.3 DEFENSE ANALYSIS EXPERIENCE

All of the experts have a considerable amount of experience in the analysis of military problems, as indicated in Table B.3. Those with an extensive Army background counted most of their time in the Army, since their work was largely analytical in nature. Thus, not surprisingly, the years of experience for defense analysis in Table B.3 are highly correlated with those for military experience in Table B.2. The individuals in this group have worked on a very wide array of research topics, ranging from military analysis of specific tactical and operational situations, to analysis in support of high-level acquisition decisions, including future force development choices.

# BIBLIOGRAPHY

Adler, Michael, and Erio Ziglio (eds.) (1996). *Gazing into the Oracle: The Delphi Method and its Application to Social Policy and Public Health.* London: Jessica Kingsley Publishers.

Bankes, Steven C. (1993). "Exploratory modeling for policy analysis." *Operations Research*, Vol. 41, No. 3, pp. 435–449.

———— (1994). "Computational experiments and exploratory modeling." *Chance*, Vol. 7, No. 1, pp.50–51, 57.

Bell, David E., Howard Raiffa, and Amos Tversky (1988). "Descriptive, normative, and prescriptive decision making." In Bell, David E., Howard Raiffa, and Amos Tversky (eds.), *Decision Making: Descriptive, Normative, and Prescriptive Interactions*. Cambridge, England: Cambridge University Press.

Bridgeman, P.W. (1922). *Dimensional Analysis*. New Haven, Conn.: Yale University Press.

Brooks, Arthur, Steven C. Bankes, and Bart Bennett (1997). *Weapon Mix and Exploratory Analysis*. Santa Monica, CA: RAND, DB-216/2-AF.

Clausewitz, Carl von (1976). (Translated by Michael Howard and Peter Paret). *On War*. Princeton, New Jersey: Princeton University Press.

Cohen, William S. (1997). *Report of the Quadrennial Defense Review*. Washington, D.C.: Department of Defense.

Cook, Major General Donald G. (1998). *Evolving to an Expeditionary Aerospace Force: The Next Air Force*. Director for AEF Implementation, U.S. Air Force.

Coombs, C.H. (1958). "On the use of inconsistency of preferences in psychological measurement." *Journal of Experimental Psychology*, Vol. 55, pp. 1–7.

———— (1964). *A Theory of Data*. New York: Wiley.

## Bibliography


Davis, Paul K. (ed.) (1994). *New Challenges for Defense Planning: Rethinking How Much Is Enough*. Santa Monica, CA: RAND, MR-400-RC.

——— and James H. Bigelow (1998). *Experiments in Multiresolution Modeling (MRM)*. Santa Monica, CA: RAND, MR-1004-DARPA.

———, ——— and Jimmie McEver (1999). *Analytical Methods for Studies and Experiments on "Transforming the Force."* Santa Monica, CA: RAND, DB-278-OSD.

——— and Donald Blumenthal (1991). *The Base of Sand Problem: A White Paper on the State of Military Combat Modeling*. Santa Monica, CA: RAND, N-3148-OSD/DARPA.

———, David Gompert, and Richard Kugler (1996). *Adaptiveness in National Defense: The Basis of a New Framework*. Santa Monica, CA: RAND, IP-155.

Dewar, James A., James C. Wendt, Sean J. A. Edwards, and Steven C. Bankes (2000). *Expandability of the 21st Century Army*. Santa Monica, CA: RAND, MR-1190-A (forthcoming).

Edwards, Ward, and J. Robert Newman (1982). *Multiattribute Evaluation*. Sage University Papers Series on Quantitative Applications in the Social Sciences, 07-026. Beverly Hills, CA: Sage.

Elachi, Charles (1998). *Mars Exploration Program: Preliminary Architecture Team Report*. Washington, DC: NASA.

Fukuyama, Francis, and Abram N. Shulsky (1997). *The "Virtual Corporation" and Army Organization*. Santa Monica, CA: RAND, MR-863-A.

Gaertner, Paul (2000). *An Application of TOPSIS for Capability Impact Assessment*. (Presentation to the Defence Operations Analysis Symposium.) Salisbury, Australia: Defense Science and Technology Organisation.

Gander, T. J. (1997). "Shouldering the burden of last-ditch defense." *Jane's International Defense Review*, Vol. 30, No. 4, pp. 57–62.

Gordon, John, IV, and Peter A. Wilson (1998). *The Case for Army XXI "Medium Weight" Aero-Motorized Divisions: A Pathway to the Army of 2020*. Carlisle, PA: Strategic Studies Institute.

## Bibliography


——— and ——— (1999). "Moving toward high performance power projection: the case for medium-weight army forces." *ARMY*, December, pp. 33–40.

Gritton, Eugene C., Paul K. Davis, Randall Steeb, and John Matsumura (2000). *Ground Forces for a Rapidly Employable Joint Task Force: First-Week Capabilities for Short-Warning Conflicts*, Santa Monica, CA: RAND, MR-1152-OSD/A.

Hillestad, Richard J., and Paul K. Davis (1998). *Resource Allocation for the New Defense Strategy: The DynaRank Decision-Support System*. Santa Monica, CA: RAND, MR-996-OSD.

Hwang, Ching-Lai, and K. Paul Yoon (1981). *Multiple Attribute Decision Making: Methods and Applications*. Berlin: Springer-Verlag.

——— and Ming-Jeng Lin (1987). *Group Decision making under Multiple Criteria: Methods and Applications*. Berin: Springer-Verlag.

Ischebeck, Otfried, and Hartwig Spitzer (1992). "Evolution of tanks and anti-tank weapons: assessment of offence-defence dynamics and arms control options." In W.A. Smit, J. Grin and L. Veronmkov (eds.), *Military Technological Innovation and Stability in a Changing World*. Amsterdam: VU University Press.

Keeney, Ralph L., and Howard Raiffa (1993). *Decisions with Multiple Objectives: Preferences and Value Tradeoffs*, 2nd edition. Cambridge, England: Cambridge University Press.

Khalilzad, Zalmay, and Ian O. Lesser (eds.) (1997). *Sources of Conflict in the 21st Century: Regional Futures and U.S. Strategy*. Santa Monica, CA: RAND, MR-897-AF.

——— and David Ochmanek (eds.) (1997). *Strategic Appraisal 1997: Strategy and Defense Planning for the 21st Century*. Santa Monica, CA: RAND, MR-826-AF.

Koury, Robert, and Andrew Loerch (1992). *Army Program Value Added Analysis 94-99 (VAA 94-99), Volume 1 – Main Report*. Bethesda, MD: Army Concepts Analysis Agency, CAA-SR-92-10.

Lempert, Robert J., and James L. Bonomo (1998). *New Methods for Robust Science and Technology Planning*. Santa Monica, CA: RAND, DB-238-DARPA.

————, Michael E. Schlesinger, and Steven C. Bankes (1996). "When we don't know the costs or the benefits: adaptive strategies for abating climate change." *Climatic Change*, Vol. 33, pp. 235–274.

Linstone, Harold A., and Murray Turoff (eds.) (1975). *The Delphi Method: Techniques and Applications*. Reading, MA: Addison-Wesley.

Louviere, Jordan J. (1988). *Analyzing Decision Making: Metric Conjoint Analysis*. Sage University Paper Series on Quantitative Applications in the Social Sciences, 07-067. Newbury Park, CA: Sage.

Macgregor, Douglas A. (1997). *Breaking the Phalanx: A New Design for Landpower in the 21st Century*. Westport, CT: Praeger.

Marsh, Robert T. (1997). *Critical Foundations: Protecting America's Infrastructures*. Washington, DC: President's Commission on Critical Infrastructure Protection.

Matsumura, John, and Randall Steeb, et al. (1997). *Analytic Support to the Defense Science Board: Tactics and Technology for 21st Century Military Superiority*. Santa Monica, CA: RAND, DB-198-A.

————, ———— and John Gordon IV (1998). *Assessment of Crusader*. Santa Monica, CA: RAND, MR-930-A.

Miller, George M. (1956). "The magical number seven, plus or minus two: some limits on our capacity for processing information." *Psychological Review*, Vol. 63, pp. 81–97.

O'Hanlon, Michael (1995). *Defense Planning for the Late 1990s: Beyond the Desert Storm Framework*. Washington, DC: The Brookings Institution.

Saaty, Thomas L. (1980). *The Analytic Hierarchy Process*. New York: McGraw-Hill.

———— (1989). "Group decision making and the AHP." In Golden, Bruce L., Edward A. Wasil, and Patrick T. Harker (eds.), *The Analytic Hierarchy Process: Applications and Studies*. Berlin: Springer-Verlag.

Sackman, Harold (1975). *Delphi Critique: Expert Opinion, Forecasting, and Group Process*. Lexington, MA: Lexington Books.

## Bibliography


Schwartz, Peter (1991). *The Art of the Long View: Planning for the Future in an Uncertain World*. New York: Currency Doubleday.

Sharoni, A. H., and L. D. Bacon (1997). "The Future Combat System (FCS)." *Armor*, July-August, pp. 7–13.

Shinseki, General Eric K. (1999). *Army Vision Statement*. http://www.hqda.army.mil/ocsa/vision.htm, last accessed April 11, 2000.

Simon, H. A. (1957). *Models of Man*. New York: Wiley.

Simpkin, Richard (1979). *Tank Warfare : An Analysis of Soviet and NATO Tank Philosophy*. London: Brassey's Publishers.

Steele, Dennis (2000). "The Army stages a Kentucky demo to define 'the art of the possible'." *ARMY*, March, pp. 20-26.

Steuer, Ralph E. (1986). *Multiple Criteria Optimization: Theory, Computation, and Application*. New York: John Wiley & Sons.

Stokey, Edith, and Richard Zekhauser (1978). *A Primer for Policy Analysis*. New York: W. W. Norton & Company.

Tavana, Madjid and Snehamay Banerjee (1995). "Strategic assessment model (SAM): a multiple criteria decision support system for evaluation of strategic alternatives." *Decision Sciences*, Vol. 26, No. 1, pp. 119–143.

Tversky, Amos, and Daniel Kahneman (1974). "Judgements under uncertainty: heuristics and biases." *Science*, Vol. 185, pp. 1124–1131.

———— and ———— (1981). "The framing of decisions and the psychology of choice." *Science*, Vol. 211, pp. 453–458.

U. S. Army (1993). *Operations*, Field Manual 100-5.

U. S. Army Armor Center (1999). Briefing to USAA Meeting.

U. S. Joint Chiefs of Staff (1994). *Joint Doctrine for Military Deception*, Joint Publication 3-58.

## Bibliography


Van Creveld, Martin L. (1982). *Fighting Power: German and US Army Performance, 1939-1945*. Westport, CT: Greenwood Press.

Von Neumann, John, and Oskar Morgenstern (1947). *Theory of Games and Economic Behavior*. Princeton, NJ: Princeton University Press.

Winterfeldt, Detlof von, and Ward Edwards (1986). *Decision Analysis and Behavioral Research*. Cambridge, England: Cambridge University Press.

Yoon, K. Paul, and Ching-Lai Hwang (1995). *Multiple Attribute Decision Making: An Introduction*. Sage University Paper Series on Quantitative Applications in the Social Sciences, 07-104. Thousand Oaks, CA: Sage.

Yu, P.L. (1985). *Multiple Criteria Decision Making: Concepts, Techniques and Extensions*. New York: Plenum.

Zahedi, Fatemeh (1986). "The analytic hierarchy process – a survey of the method and its applications." *Interfaces*, Vol. 16, No. 4, pp. 96-108.

Zeleny, Milan (1982). *Multiple Criteria Decision Making*. New York: McGraw-Hill.